

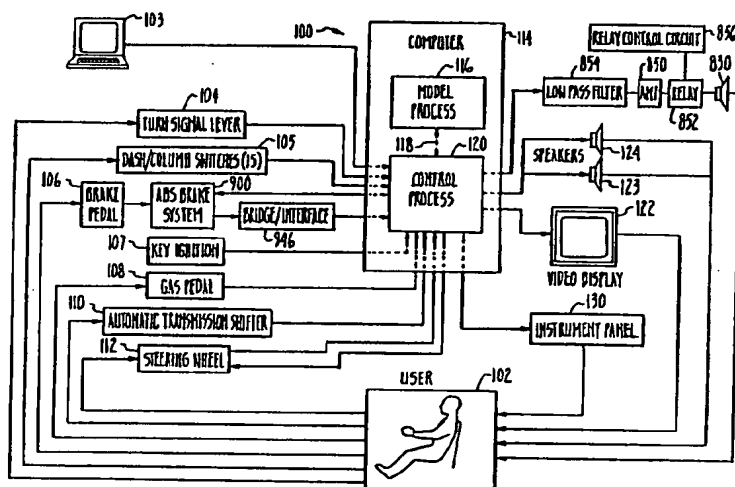


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(54) Title: DRIVER TRAINING SYSTEM WITH PERFORMANCE DATA FEEDBACK**(57) Abstract**

A driver training system (100) for a user (102) of a simulated vehicle. The system (100) includes input devices (104-112) for controlling the simulated vehicle, a video display (122) having three-dimensional graphics, a computer (114), modeling software for determining position information based on the input devices, atmospheric effects software to simulate time-of-day and weather conditions, realistic operating feedback software for simulating on the input devices the feedback normally experienced with operating the vehicle, and recursive training software to display a previous route (180) through an environment simultaneously with a present route (192) through the environment together with associated performance data (182-188). Another aspect of the recursive training software replays either the previous route (180) or present route (192) and controls one of the input devices (112) to provide "hands-on" feedback to the user (102). The user (102) then incrementally and recursively maximizes parameters associated with vehicle operation skill. The preferred embodiment includes a low frequency sound system (800) having a low frequency speaker (830) mounted on an enclosure (828) adjacent to the simulation user's seat (802) through which road feel cues such as hitting an object are transmitted to the user (102) in response to signals received from the computer (114). Another aspect of the invention is a system (900) for simulating the feel to the user (102) of anti-lock brakes on a brake pedal (106) in response to signals received from the computer (114). The driver training system (100) may be embodied as a vehicle simulator.



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DRIVER TRAINING SYSTEM WITH PERFORMANCE DATA FEEDBACKField of the Invention

5 The present invention generally relates to automated training and, more particularly, is concerned with vehicle simulators.

Background of the Invention

10 A vehicle simulator can be defined as a system that simulates the operating conditions of a vehicle in an environment. Where the vehicle simulated is an automobile, the vehicle will usually include the typical automobile controls such as a steering wheel, a gear shift, an accelerator pedal, and a brake pedal. Generally, this vehicle
15 will be simulated in an environment which will typically include a road. The environment in this case may also include weather conditions such as fog or snow. Besides cars, examples of other types of vehicles that may be simulated include airplanes, ships, submersibles and space vehicles.

20 Vehicle simulators provide a means to efficiently train operators of a vehicle. The operator of a vehicle can safely learn, from the simulator, how the vehicle will operate in a given set of conditions without actually exposing the operator to any of the risks inherent in real world operation of the
25 vehicle. The experience garnered through making mistakes on a simulator is invaluable when compared to the inherent risks of vehicle damage and operator injury associated with making a driving error in a real-life situation. For example, in a police training application, a student could learn the limits
30 of a police cruiser or guidelines for pursuit, and be tested in these areas without the associated risks of real-life training.

 In some sense, a simulator achieves a balance between testing the operator's knowledge of the "rules of the road"
35 and testing the operator's use of a vehicle. Testing the operator's knowledge is typically and conveniently accomplished through written and/or verbal examinations.

However, examinations are of limited usefulness for operator training. For example, operator reflexes are not tested at all, and, moreover, such examinations do not adequately address the skills necessary for real-time decision-making.

5 In addition to concerns relating to operator safety and vehicle damage, training through actual vehicle operation has other pitfalls. First, the cost of instructor time may be prohibitive. Furthermore, a specific vehicle, such as a space or underwater vehicle, may simply not be available for
10 training purposes. Lastly, there is always the risk of an accident when a student is training on an actual vehicle under realistic conditions. Although a certain amount of training may occur in benign environments, for example, learning to drive a car in an empty parking lot, there comes a time, early
15 in the operator's training, where driving in an unrealistic environment is no longer useful and practical.

 Vehicle simulators address the issue of presenting the operator with a realistic training environment. The principal shortcoming of existing training systems, however, is that
20 they do not provide realistic feedback for incremental learning. For example, in most known systems there is no way to instantaneously gauge one's progress against a prior use of the vehicle while it is in operation.

 Video arcade games are another technology providing a
25 certain degree of user feedback. Arcade games are typically placed in public areas such as arcade halls, theaters, airports and other such areas where the users can occupy time and entertain themselves by playing the game. Arcade games utilizing video displays have been around for some time now,
30 beginning with the simplistic game of bouncing a ball across a line with paddles known as "Pong". However, with the passage of time, video arcade games have become ever more sophisticated and realistic.

 Since arcade games have housings which occupy a limited
35 space, the computer equipment of the game is subject to strict space constraints. In addition, the user's interest must be captured and maintained by the simulator, thus requiring that

processing be accomplished in real-time. The competing space and time goals thus make the task of injecting realism into the games more difficult.

5 In many senses, the arcade game called "Hard Drivin'TM",
manufactured and distributed by Atari Games Corp. of Milpitas,
California, represents the state of the art in arcade game
realism. The physical layout of the game includes clutch,
brake and gas pedals, a gearshift and a steering wheel. The
user, or driver, is provided feedback response from a video
10 display having a three-dimensional graphical representation of
the driving environment and from a speaker which generates
realistic sounds of driving. A digital processor, comprising
a number of microprocessors and a memory, is the interface
between the user inputs and the feedback response.

15 The training potential of a simulator or arcade game is
maximized when the student has user feedback. One form of
feedback possible is a display of various performance numbers
on a video monitor of the simulator or game. These
performance numbers might be elapsed time for completing a
20 track, top speed, points, and so forth. However, this type of
information does not inform the student exactly what
location(s) and what parameter(s) he may need to improve.
Additionally, graphical feedback attracts and holds the
student's attention better than a number or a series of
25 numbers. Therefore, a need exists for graphical feedback of
performance data that shows the student periodically how he
compares to a standard set by an instructor, or where and what
parameters he needs to improve to attain a standard set by an
instructor. A need also exists for realistic vehicle
30 simulators and arcade games to provide personalized feedback,
wherein the feedback may be personalized by either the
operator/user or by an instructor/champion.

To enhance the effectiveness of the training afforded by
vehicle simulators, there is a need to ensure that the
35 simulator realistically simulates both the feel of operating
the vehicle, as well as realistically simulating the effect of
operating the various vehicle controls, in specific

situations. Realistically simulating the feel of operating a vehicle includes simulating the feel of the vehicle as it travels in a simulated environment as well as simulating the feel of the various vehicle controls during actual usage. If the input devices feel and work like the real thing, the student should encounter minimal difficulties due to the input devices when moving from a simulator to a real vehicle. For a car, truck or similar vehicle, several controls are mounted on the steering column. These controls frequently are a gearshift lever and a turn signal lever. The turn signal lever is moved by the driver to activate a turn signal indicator until the turn is substantially complete, at which time a canceling mechanism deactivates the turn signal indicator. The shift lever has an indicator, which moves in response to a shift of gear by the driver, that shows what gear is selected. Thus, a need exists for simulator or arcade game input devices that feel and work like those in a real vehicle.

In automobile simulators the effectiveness of the training given by the simulator would be enhanced if the simulator could translate to the operator the feeling of a wide variety of road surfaces and objects that an automobile is likely to come in contact with. Specifically, there is a need for a system that will generate a wide variety of road feel cues based on where the simulated automobile is within a simulated universe and what the simulated automobile contacts within that universe.

One example of where a prior art simulator has attempted to simulate the feeling of a vehicle operating in an environment is shown in U.S. Patent No. 4,574,391 to Morishima. Morishima discloses a sound system for a video game, configured for giving a live action feeling to a game involving artillery. This sound system includes several audio speakers mounted around the user's head as well as a low frequency speaker mounted underneath the user's seat. The live action feeling is generated by having the audio speakers generating artillery sound in sequence thereby creating the

illusion of the artillery shell approaching and, when the round hits, sending low frequency components of the explosion sound to the low frequency speaker mounted underneath the user's seat. The low frequency speaker then causes the seat to vibrate as a direct result of an explosion sound.

One shortcoming of the system disclosed in Morishima is that the seat vibration and the sound of the explosion are not generated independently. That is, the vibration is a direct result of the low frequency components of the sound of the explosion. Generating physical feedback by transmitting the low frequency component of an associated sound limits such feedback to only sound events having a sufficiently large low frequency component to cause the seat to vibrate. Consequently, the feel of events which occur during the simulation which do not have a large low frequency component cannot be represented to the user. Hence, there is a present need for a system which is capable of simulating a vehicle in a specific environment and, which is capable of providing physical feedback based on a variety of simulated events which are not always accompanied by a sound including a large low frequency component.

In automobile simulators, the effectiveness of the training given by the simulator would be further enhanced if the feel of the brake pedal to the operator closely approximated the feel of an actual brake pedal in an actual car when the brake pedal is depressed. Further, the effect of depressing the brake pedal a given amount in the automobile simulator, as perceived by the operator (or user), should also closely approximate the effect that depressing the brake pedal the same amount has in a real-life automobile.

Many of today's automobiles are equipped with an antilock brake system (ABS). An ABS is a safety feature added to automobiles to enhance the controllability of automobiles during braking maneuvers. When non-ABS brakes are suddenly applied, or applied with great force, the brakes may lock up and consequently the automobile will often enter into an uncontrollable skid. An automobile tire will skid over

pavement when the forward momentum of the automobile exceeds the velocity of the tire, thereby dragging the tire forward over the pavement in a skidding fashion. An ABS acts to prevent such uncontrollable skids by sensing when the tire is being dragged over the pavement, and then decreasing the amount of stopping pressure exerted by the brakes against the wheel by an amount just sufficient to permit the tire to continue to roll over the pavement while still slowing the rotation of the tire. The ABS will then typically oscillate between increasing and decreasing the amount of braking force exerted against the tire as the ABS tries to slow the rotational velocity of the tires, while also preventing the brakes from locking up. This oscillation results in a unique, vibratory pulsation of the brake pedal during braking.

Currently, no known vehicle simulators simulate the feel, or the effect, of ABS brakes. However, a person driving an automobile equipped with ABS brakes may become startled when they first experience the feeling of a brake pedal of a vehicle which is equipped with ABS brakes and, as a consequence, stop braking the vehicle when braking is necessary. Hence, the lack of a simulator which will simulate an automobile equipped with ABS brakes represents an additional shortcoming in the prior art relating to driving training simulators.

Simulator training would be improved if accurate atmospheric conditions could be reproduced by a vehicle simulator. Atmospheric conditions caused by particles in the air or the position of the sun in the sky, for example, will mute and distort the environmental colors perceived by a driver. The change in coloration can be thought of as resulting from a screen or grid of haze being overlaid on the image. Such a visual cue of color change, henceforth termed hazing, would provide a greater degree of realism in simulators, allowing users to test their driving abilities under varying environmental conditions.

Night driving is another condition in which it is desirable to practice and test driving abilities. As objects

are illuminated by the headlights, they become visible out of the darkness. Then, as the user approaches the objects, they appear brighter and easier to perceive. A problem some drivers may have is driving at a speed that doesn't allow safe
5 stopping if an object would be in the roadway beyond the illumination range of the headlights. It would be desirable to safely experience such an effect on a simulator and therefore know how to handle the situation in real-life. Thus, a simulator which provides the capability to emulate
10 time of day, e.g., dawn, day, dusk, or night, and weather, e.g., fog or snow, would give the user a chance to experience most any driving condition.

Hazing, or simulating non-optimal atmospheric conditions, is used in some present military simulators to simulate flying
15 in fog, or some other form of haze. However, the known military simulators require expensive computer hardware, including high resolution video displays, to reproduce these effects.

Moreover, with infinite resolution on a video display, the simulation of atmospheric conditions such as fog, smog, dusk, and the like, would be perfect, i.e., fine droplets or granules could be interleaved with the view. Alternatively, the human eye could be deceived into seeing higher video resolutions than actually available by employing higher rates
20 of video frame update. Unfortunately, most present video systems have limited resolution and slow rates of video update. In addition, the choice of colors in video displays is often limited due to constraints on video memory.

Due to the above-mentioned problems, users desiring
30 realistic training having visual cues which change colors according to atmospheric conditions have either had to have access to expensive equipment or have had to simply do without. A driving simulator having the capability to approximate atmospheric conditions using many readily
35 available and reasonably priced video display systems would therefore be a great benefit in training drivers.

Summary of the Invention

The aforementioned needs are satisfied by the present invention which is implemented on a driver training system for a user of a simulated vehicle. This driver training system is comprised of a plurality of simulated input devices for controlling the operation of the simulated vehicle, and includes a video display for presenting the user with a view of a simulated environment, and a means responsive to the input from the input devices for modeling the position and the operating characteristics of the vehicle within the simulated environment.

In one preferred embodiment of this invention the simulated vehicle is an automobile. The system of this embodiment includes means for determining when the vehicle in the simulated universe is at a point where a road cue should be transmitted to the user. At this point the system recalls a digital signal of the road cue out of a memory, translates it into an analog signal, which is then low pass filtered and amplified. The amplified low frequency signal is then sent to a low frequency speaker where the speaker's diaphragm is in communication with a body of air confined within an enclosure coupled to a user's seat. The signal will then cause the speaker diaphragm to vibrate which in turn causes the air within the enclosure to translate and be compressed. The compression and translation of the air within the enclosure causes a semi-rigid diaphragm consisting of a piece of flexible material, which is an integral part of the enclosure, to vibrate. Since the seat upon which the user sits is coupled to the semi-rigid diaphragm, vibrations of the semi-rigid diaphragm will be felt by the user.

In another aspect of this invention, there is a system which is configured for use with automobiles, which will sense when the user of the simulator has applied the brakes in such a manner that an ABS braking system would be activated in a real-world automobile. This system then will induce mechanical vibrations and pulsations on the brake pedal, to simulate the brake pedal response that occurs under the same

braking conditions in a real-world automobile that is equipped with ABS brakes.

5 The present invention includes a driver training system for a user of a simulated vehicle, comprising a plurality of simulated input devices for controlling the simulated vehicle, a video display for presenting the user with a view of a simulated environment, modeling means responsive to the input devices for determining position information of the simulated vehicle in the simulated environment, means responsive to the position information for displaying on the video display a present route of the simulated vehicle through the simulated environment, and means responsive to at least one of the simulated input devices for displaying on the video display a plurality of states of the input device at selected times in the present route.

10 In another aspect of the present invention there is a driver training system for a user of a simulated vehicle, comprising a plurality of simulated input devices for controlling the simulated vehicle, a video display for presenting the user with a view of a simulated environment, modeling means responsive to the input devices for determining position information of the simulated vehicle in the simulated environment, means responsive to the position information for displaying on the video display a present route of the simulated vehicle through the simulated environment, means for storing the present route and a plurality of states of at least one input device in a memory, and means for replaying the present route on the video display and moving the input device according to the states stored in the memory.

20 In another aspect of the present invention, there is a computer having a video display, a method of hazing a plurality of polygons, comprising the steps of selecting one of the polygons, calculating a haze value as:

$$\text{haze value} = (z * k_{\text{val}}) / \text{dimval}$$

30 where

z is the distance between the camera position and the polygon,

kval is a constant, and

dimval is the distance for full hazing,

calculating a shade value as the dot product of a sun vector and the normal to the polygonal plane, indexing a dither table with the haze and shade values for dither color offsets, adding a base color to the dither color offsets for dither colors, determining a dither pattern of dither colors based on the position of the selected polygon, and drawing the selected polygon on the video display using the dither pattern.

10 In another aspect of the present invention, there is a turn signal assembly for a steering wheel, comprising a lever, a frame, a retainer plate rigidly connecting to one end of the lever and axially coupled to the frame about a pivot point, a plunger mounted in a bore in the frame wherein the plunger is
15 biased, means in the assembly for selectively engaging detents in the retainer plate, and a cancel pin connected to a hub area, the hub area connected to the steering wheel so that the cancel pin forces the plunger into the bore when the hub area is turned one direction, and pushes against the released
20 plunger when the hub area is turned the other direction thereby forcing detent disengagement and reengagement.

In yet another aspect of the present invention, there is a low frequency sound generator, comprising a set of input devices, a computer for receiving input signals from the input
25 devices, a control process executed by the computer for selectively converting the input signals into output signals indicative of a simulated environment, a low pass filter for filtering the output signals, an amplifier for amplifying the filtered signals, a speaker for receiving the amplified
30 signals and generating low frequency sounds, and a housing having a bladder filled with air wherein the speaker is secured to the housing so as to be in mechanical communication with the air in the bladder.

In another aspect of the present invention, there is a
35 driver training system for a user of a simulated vehicle, comprising a plurality of simulated input devices for controlling the operation of the simulated vehicle, modeling

means responsive to the input devices for determining position information of the simulated vehicle in a simulated environment, a video display for presenting the user with a view of the simulated environment, means for providing
5 feedback to the user through a selected one of the simulated input devices, and means, responsive to the position information, for providing low frequency sound to the user.

In yet another aspect of the present invention, there is a low frequency sound system, comprising a seat, a plurality
10 of input devices, a computer for receiving input signals from the input devices, a control process executed by the computer for selectively converting the input signals into a plurality of output signals, and a transducer for communicating the output signals to the seat.

In still another aspect of the present invention, there is a system for simulating the physical sensations of a brake pedal during operation of an antilock braking system, comprising means for detecting when the brake pedal is depressed, means, responsive to the detecting means, for
15 determining the activation of an antilock braking system, and means, responsive to the determining means, for providing feedback indicative of an antilock brake system to the brake pedal.
20

These and other objects and features of the present
25 invention will become more fully apparent from the following description and appended claims taken in conjunction with the accompanying drawings.

Brief Descriptions of the Drawings

Figure 1 is a block diagram of one presently preferred
30 driver training system of the present invention;

Figure 2 is a perspective illustration of a user's view while maneuvering through a lane change course on a steering track corresponding to a video screen display provided by the
35 driver training system of Figure 1;

Figure 3 is a top plan view of the lane change course shown in Figure 2;

Figure 4a is a diagram of a summary evaluation screen of an instructor's path through the lane change course shown in Figure 3;

5 Figure 4b is a diagram of a summary evaluation screen of a student's path superimposed upon the instructor's path through the lane change course shown in Figure 3;

Figure 5 is a diagram of the user's view while in replay mode through the lane change course shown in Figure 3;

10 Figure 6 is a "bird's-eye" view of a user's simulated vehicle while in replay mode through the lane change course shown in Figure 3;

Figure 7 is a diagram of a main menu screen of the driver training system shown in Figure 1;

15 Figure 8 is a diagram of a track menu screen of the driver training system shown in Figure 1;

Figure 9 is a diagram of a vehicle menu screen of the driver training system shown in Figure 1;

Figure 10 is a diagram of a weather menu screen of the driver training system shown in Figure 1;

20 Figure 11 is a diagram of an instruction options menu screen of the driver training system shown in Figure 1;

Figure 12 is a flow diagram of the "executive_control" function which forms a portion of the control process shown in Figure 1;

25 Figure 13 is a flow diagram of the "init_precord" function used by the "executive_control" function shown in Figure 12;

Figure 14 is a flow diagram of the "cones" function used by the "executive_control" function shown in Figure 12;

30 Figure 15 is a flow diagram of the "summary_evaluation" function used by the "cones" function of Figure 14;

Figure 16 is a flow diagram of the "replay_ideal_path" function used by the "cones" function of Figure 14;

35 Figure 17 is a flow diagram of the "replay_student_top_view" function used by the "cones" function shown in Figure 14;

Figure 18 is a flow diagram of the "save_ideal_path"

function used by the "cones" function shown in Figure 14;

Figure 19 is a flow diagram of the "replay_speed" function used by the "cones" function shown in Figure 14;

5 Figures 20a, 20b and 20c are diagrams of screen displays showing the approximation of atmospheric conditions aspect of the driver training system shown in Figure 1;

10 Figure 21 is a flow diagram of the approximation of atmospheric conditions or "atmospheric_effects" function used by the "display_objects" function of the "executive_control" function shown in Figure 12;

Figure 22 is a diagram of a set of mechanical input devices and an instrument panel for the simulated vehicle of the driver training system shown in Figure 1;

15 Figure 23 is a diagram of a turn signal assembly for the turn signal lever shown in Figure 22;

20 Figure 24 is a side elevational view of one presently preferred embodiment of a seat and low frequency speaker assembly for the driver training system wherein the speaker is mounted in a floor mounted base, shown in cross-section, under the seat;

Figure 25 is a top plan view of the base of the low frequency speaker assembly taken along line 25-25 of Figure 24;

25 Figure 26 is an electrical schematic showing one presently preferred embodiment of a relay control circuit which is connected to the low frequency speaker shown in Figure 24;

30 Figure 27 is a side elevational view of another presently preferred embodiment of a seat and low frequency speaker assembly for the driver training system of the present invention wherein the speaker is mounted in the back of the seat; and

35 Figure 28 is a cross-sectional side view of the mechanical structure of one presently preferred embodiment of an ABS brake simulation assembly of the present invention.

Detailed Description of the Preferred Embodiments

Reference is now made to the drawings wherein like numerals refer to like parts throughout.

Figure 1 shows one presently preferred embodiment of a driver training system 100 of the present invention. The driver training system 100 is operated by a user or student 102 (shown schematically), who desires to improve driving performance. It should be understood that the driver training system 100 as hereinafter described is applicable to any type of vehicle that is operated by a human. The present invention includes a personalized feedback response that is easily generalized to driver training systems for all kinds of simulated vehicles and all types of driving.

The more specific embodiment of the driver training system 100 as presented in the following figures and description is presented as a vehicle simulator for police training. At times, the user 102 will be an instructor, rather than the student, when it is desired to establish an "ideal" path, as will be described hereinbelow.

In Figure 1, the user 102 preferably sits in a booth or housing (not shown) such as the one described in the assignee's U.S. patent entitled "Rear Entry Booth and Adjustable Seat Apparatus for a Sit-Down Arcade Video Game", U.S. Patent No. 4,960,117. In that way, distractions are minimized and the user 102 can concentrate on self-improvement of his driving technique. The sitting position also better simulates the actual conditions associated with driving a vehicle.

In the driver training system 100, the user 102 moves a turn signal lever 104, manipulates a plurality of dash and column switches 105, manipulates a key turned ignition switch 107 for starting the simulated automobile, depresses a brake pedal 106 which is part of a simulation antilock brake system (ABS) 900 and depresses a gas pedal 108 in the customary manner. In addition, an automatic transmission shifter 110 is manipulated by the user 102 to select a reverse gear or one of a plurality of forward gears. A steering wheel 112 is turned by the user 102 so as to guide the simulated vehicle in the

desired direction of travel.

The mechanical inputs provided by the user 102 to the input devices 104, 105, 108, 110 and 112 are translated by transducers into electrical signals which are fed into a computer 114. The mechanical inputs on the brake pedal 106 are translated into electrical signals by the ABS brake system 900 and the signals are fed to a bridge interface circuit 946 connected to the computer 114. The computer 114 further receives both inputs and downloaded programs from a personal computer (PC) 103 which is preferably an IBM compatible computer having a 100 megabyte hard drive and a 4 megabyte RAM. The personal computer 103 and the computer 114 are interactively connected via a communication link 140. The link 140 should be capable of handling high speed digital data transmissions, on the order of 10 megabits per second, and it preferably includes a communication circuit such as an ADSP 2105 or 2101 manufactured by Analog Devices to ensure sufficiently rapid communication between the computer 114 and the personal computer 103.

In the presently preferred embodiment, the computer 114 includes a general purpose microprocessor such as a Motorola 68000 (not shown) or another member of the Motorola 680x0 microprocessor family. One function of the 68000 microprocessor is palette manipulation. In addition to the 68000 microprocessor, the computer 114 preferably includes a model processor (DSP), such as an AT&T DSP32C, a digital signal processor (ADSP), such as an Analog Devices ADSP-2101, and a graphics processor (GSP) such as a Texas Instruments 34010 Graphic System Processor, none of which are shown. The DSP performs velocity, acceleration, and position calculations. The ADSP provides the "higher-level" functions of video display such as translation, rotation, scaling, and shading while the GSP efficiently performs dither patterning, rendering, and the low-level graphics work of writing polygons (so-called polygon graphics) to the video display 122.

The presently preferred computer 114 also includes a read only memory (ROM) comprising 256 kilobytes of storage for self

test; as well as a random access memory (RAM) comprising: 1.75 megabytes for downloaded programs, object definition data, and graphics universe data, an additional 0.5 megabytes of shared memory for additional downloaded graphics object data, shared
5 with the 68000 processor. The center monitor in the video display 122 (Figure 1) also includes an additional 1 megabyte of RAM for downloaded scenario traffic data. Furthermore, the presently preferred computer 114 also incorporates additional random access memories for each processor as follows: DSP - 64
10 kilobytes; ADSP - 12 kilobytes of program memory (for the programs downloaded from the personal computer 103), 16 kilobytes of buffer memory; and GSP - 45 kilobytes of program memory (for the programs downloaded from the RAM or the personal computer 103) and 640 kilobytes of display memory.
15 The GSP further employs video random access memory (VRAM) for improved video display rates.

The computer 114 executes computer software which is stored in a memory (not shown) such as a 128k X 8, 70-100 nanosecond Random Access Memory (RAM). The software executed
20 by the computer 114 that is stored in this RAM can be one of a number of software scenarios of programs relating to driving stored within the PC 103 which can be downloaded into the RAM in response to commands executed at the PC 103. The computer software executed by the computer 114 is logically organized
25 to include a control process 120.

The control process 120 receives digitized signals from the input devices 104-112 as well as other digitized input signals from the personal computer 103. The control process 120 then passes data from these digitized signals, across a
30 data path 118, to a model process 116 that models the velocity and acceleration vectors of the simulated car. Thus, at a time T, position data, i.e., the Cartesian coordinates of the car, are determined by the model process 116. The position data is made available, across the data path 118, back to the
35 control process 120. Accordingly, the control process 120 applies the "rules of the road" to the new position of the car, and initiates signals to drive a video display 122, a

pair of speakers 123 and 124, a low pass filter 854 and an instrument panel 130. The filter 854 provides a low pass filtered signal to an amplifier 850 which is connected to a relay 852, which in turn is connected to a speaker 830 positioned adjacent to a user's seat 802 (Figure 24) or to a speaker 881 positioned adjacent to a seat 882 (Figure 27) in the two disclosed embodiments. The relay 852 is preferably a low voltage relay manufactured by Potter & Brumfield, model no. T70L5D, and is further coupled to a relay control circuit 856 which disconnects the speaker 830 when the system 100 is either powering up or down.

The control process 120 further provides a user viewpoint into a graphical representation of the vehicle universe. In the preferred vehicle simulation embodiment, the computer 114 generates polygon graphics to the video display 122. One preferred video display device, such as model no. 25K7191 available from Wells-Gardner of Chicago, Illinois, is a multi-synchronous display that can be configured to display 512 x 288 pixels. The video display 122 may include a plurality of video devices arranged in a semi-circle to give the user 102 a simulated view similar to that of a real car. This arrangement is described in the assignee's copending U.S. patent application entitled "Modular Display Simulator", Serial No. 07/704,373.

The video display 122 preferably generates a color, three-dimensional graphical representation of the environment, i.e., the user's perspective of a graphical universe including items such as a roadway. The speakers 123 and 124 produce sounds such as gear changes, engine revving, skidding, and so on. The low frequency speaker 830 is preferably mounted adjacent to the seat 802 (Figure 24) to simulate feel of the road. The instrument panel 130 includes a speedometer to indicate the speed of the simulated vehicle, an indicator for the gear selected by using the shifter 110, left and right arrow lights to indicate a direction selected by using the turn signal lever 104, and various other indicator lights. Thus, the user 102 is presented with real-time feedback from

the output devices 122, 123, 124, 130 and 830 that is personalized according to his own individual performance and what he encounters in the simulated universe.

5 The control process 120 further provides feedback to simulate the feeling of a steering wheel in a real automobile while being driven. This is preferably accomplished in the same manner as described in assignee's patent "Control Device such as a Steering Wheel for Video Vehicle Simulator With Realistic Feedback Forces", U.S. Patent No. 5,044,956. The
10 control process 120, in response to inputs from the ABS 900 via a bridge interface circuit 946, also provides feedback to the brake pedal 106 with the ABS 900 thereby simulating the feeling of brakes on an automobile equipped with an ABS on the brake pedal 106.

15 The basic operation of the simulator system 100 will now be described. A simulation program is downloaded from the personal computer 103 to the computer 114 which will execute the program. The computer 114 then generates a graphics universe to be displayed to the user 102 via the video display
20 122 along with associated sounds via the speakers 123, 124. The user 102, in response to what he sees in the video display 122 and what he hears from the speakers 123, 124 manipulates the driving controls to thereby drive the simulated vehicle. Basically, the user 102 starts the automobile via the ignition
25 switch 107, puts the automobile in gear via the automatic transmission shifter 110, depresses the gas pedal 108 to make the automobile move, depresses the brake pedal 106 to make the car stop and steers the automobile with the steering wheel 112.

30 In response to the user inputs provided via the input devices 104 - 112, the control process 120 of the computer 114 passes data to the model process 116 via the data path 118 which enable the model process 116 to model the velocity and acceleration vectors of the simulated vehicle thereby
35 determining the Cartesian coordinates of the vehicle. This data is then passed back to the control process 120 via the data path 118 and is then used by the control process 120 to

provide additional signals to the user 102. For example, the Cartesian coordinates as determined by the model process 116 may determine that the user 102 has driven the simulated vehicle over a cone in the simulated universe, hence the control process 120 causes the speaker 123, 124 to generate an appropriate noise, cause the feeling of hitting a cone to be generated and felt by the user 102, via the low frequency speaker 830, as well as cause the steering wheel 112 to vibrate in the hands of the user 102 in response to hitting the cone. Further, the control process 120 will also provide feedback to the user 102 through the ABS brake system 900 when the user 102 applies the brakes sufficiently hard to enable the system.

Figure 2 is a diagram of a video screen display showing one example of a course upon which the user 102 (Figure 1) may operate the vehicle. The user 102 may be a student. From the first person viewpoint of Figure 2, it is seen that the user 102 is "placed inside" of the vehicle being simulated in the position of an observer. The user 102 views a three-dimensional simulated graphical universe 139 as projected onto the two dimensional screen of the video display 122. The scene represented in Figure 2 is one wherein the user 102 is looking forward out of a windshield while driving the simulated vehicle and proceeding on the track.

In this embodiment of the present invention, the user 102 is presented with a course 142, which is a specific instance of the universe 139. The student 102 has a basic objective of trying to drive through the course at a desired speed without hitting any obstacles, e.g., a configuration of cones 143. The computer 114 will also cause an appropriate background to be displayed. In the illustrated case, this is a cityscape 144 framed against a blue sky 146. This and other tracks, having different configurations or objectives, e.g., teaching the user 102 how to pursue other cars in traffic, can be selected by the user 102 or downloaded, preferably by the instructor, from the personal computer 103. Since the presently preferred system 100 of the present invention does

not use a timer or score points, the student 102 will not feel a need to drive as fast as possible, but instead, will concentrate on learning proper technique.

5 In such an embodiment, the driving instructor drives a course on a track to establish the "ideal" path. The student 102 then drives the course and compares his path and performance to the path and performance of the instructor. Since the ideal path is created by a real person (not computer generated) on the same driver training system 100 as the
10 student 102 uses (no machine differences), the student 102 feels that the ideal path is attainable. Furthermore, the instructor can easily tailor a path through a course to emphasize a technique or account for a condition, which needs to be emphasized for one or more specific students.

15 In one preferred embodiment of the system 100, there is an abort/select rocker switch and a cursor rocker switch (not shown) that are part of the dash and column switches 105. When the abort/select rocker switch is pressed down, a select or enter operation is initiated. When the abort/select rocker switch is pressed up, an abort operation is initiated. In
20 another preferred embodiment of the system 100, there is an enter rocker switch, a select rocker switch, and an abort rocker switch (all not shown), which are part of the dash and column switches 105, mounted adjacent the instrument panel 130 (Figure 1). The enter rocker switch corresponds with the downward position of the previously described abort/select rocker switch, while the abort rocker switch corresponds with the upward position of the abort/select rocker switch. The select rocker switch corresponds to the cursor rocker switch.
25 The enter and select rocker switches permit the user 102 to choose among various menu choices discussed hereinbelow. The abort rocker switch enables the user to end a simulation while the simulation is running. The abort rocker switch is also used to return from a submenu to the previous menu if the user
30 has not pressed the enter rocker switch.

35 A main menu (shown in Figure 7) is displayed on the video display 122 at the beginning of a simulation. The system 100

then allows the student 102 a choice as to the type of track to run. The selected track can be a steering track 140 (shown in Figure 3), a judgement track for developing quick reactions, a roadway having intersections and signal lights, an autocross track, and so on. The steering track 140 has three courses on it and the judgement track has two courses on it. The course shown in Figure 2 is part of the steering track 140 and is called a lane change course 142. As another option, and in the preferred embodiment, the system 100 allows the student 102 to select from a number of different models of the simulated vehicle. In a driver training system embodiment of the present invention, the cars to select from preferably include simulations of the vehicles used for actual road driving. The system 100 also allows the student 102 to choose the weather conditions, which in this embodiment also includes time of day conditions, e.g., dusk. Then by selecting "Start Scenario", the student 102 begins driving the simulated vehicle.

In order to better understand the lane change course 142 of Figure 2 and the steering track 140, reference is made to Figure 3 showing a top plan view of the track 140. When the student 102 (Figure 1) operates the system 100 and selects the steering track 140, the student's view is looking ahead at several sets of white cones 150 arranged in two parallel rows. The student 102 selects a course on the steering track 140 by driving to one of the areas between the two rows of white cones and enters an area called the white cones rectangle 152. This rectangle 152 is not visible on the video screen 122 (Figure 1), but is used by the computer 114 for initialization as will be described later in conjunction with the flowcharts. Proceeding forward, the student 102 enters a record rectangle 154, at which time various parameter values, which will be described hereinbelow, are recorded by the computer 114 (Figure 1). The student 102 then enters the evaluation rectangle 156 that denotes the area for which the parameter values recorded by the computer 114 will be graphically displayed, as will also be described hereinbelow. Neither of

the rectangles 154, 156 is visible on the video display 122, but their perimeters are stored in the computer 114.

Continuing to refer to Figure 3 and further referring to the system 100 shown in Figure 1, the student 102 attempts to
5 drive between two rows of parallel orange cones 160 without running into any of the cones. If the student 102 hits a cone, e.g., cone 160', the cone 160' will fall over, but the student 102 can continue driving unimpaired. After exiting the cones 160, the student 102 must turn the steering wheel
10 112 to the right and then straighten the steering wheel 112 in preparation to approach a second set of orange cones 162. After driving between the two parallel rows of cones 162, the student 102 must then turn the steering wheel 112 to the left and then straighten the steering wheel 112 in preparation to
15 approach a third set of orange cones 164. After driving between the two parallel rows of cones 164, the student 102 must then turn the steering wheel 112 to the right and then straighten the steering wheel 112 in preparation to approach a fourth set of orange cones 166. After driving between the
20 two parallel rows of cones 166, the student 102 then depresses the brake pedal 106 to stop the simulated vehicle. This stop will be beyond the end of the evaluation rectangle 156, but still inside the record rectangle 154. Once the simulated vehicle stops, and the student is on the steering track 140 or judgement track, an instruction options menu is displayed on
25 the video display 122. This menu gives the student 102 various choices, e.g., summary evaluation, to help evaluate his performance on the just completed course.

Referring back to Figure 2, the student 102 is on the
30 lane change course 142 at a point partially through the set of cones 162. The view of the student 162 shows the next two sets of cones 164 and 166. To properly negotiate the course the student 102 will soon need to start turning the steering wheel 112 to the left.

35 Figure 4a is a diagram of a summary evaluation screen 178 showing a top plan view of an instructor's path 180 through the lane change course 142 (Figure 3) along with a graphical

presentation of some of the data recorded for this path in the evaluation rectangle 156. The path 180 is plotted only for the time that the simulated vehicle is inside the evaluation rectangle 156. The direction of travel on the video display 122 (Figure 1) is from left to right. A similar video screen is displayed by the system 100 as selected by the user 102 for each of the different courses on the steering track 140 (Figure 3) and the judgement track (not shown). In the presently preferred embodiment, as the simulated vehicle is driven through the record rectangle 154 and the evaluation rectangle 156, data is recorded for various parameters at approximately 1/5 second intervals.

The display screen includes four areas of information: a steering graph 182, a path display area 184, an acceleration/braking area 186, and a velocity area 188. The steering graph 182 shows the position of the steering wheel 112 (Figure 1) in relation to a center position (indicated by a dashed line). Thus, if the simulated car is driven in a straight line, the steering graph 182 is a horizontal line in the middle of the graph. When the steering wheel 112 (Figure 1) is turned to the right of the center position by the user 102, the plot on the steering graph will dip below the middle of the graph in proportion to the speed and extent of the turn made by the user. Similarly, as the user 102 turns left of the center position of the steering wheel 112, the plot of the steering graph 182 will rise above the middle of the graph.

The path display area 184 shows the path 180 taken by the instructor through the four sets of cones 160, 162, 164, and 166 in the evaluation rectangle 156 (Figure 3). The acceleration/braking area 186 shows when the instructor depressed the brake pedal 106 by the start of a shaded bar 190 and the release of the brake pedal by the end of the shaded bar 190. Similarly, a bar of different shading 191 shows when the gas pedal 108 (Figure 1) is depressed and released by the instructor. The velocity area 188 displays the velocity of the simulated vehicle in miles per hour (mph) as it is driven through the evaluation rectangle 156. The computer 114 spaces

the velocity values so that the values are easy to read.

Figure 4b is a diagram of the summary evaluation screen showing a top plan view of a student's path 192 superimposed upon the instructor's path 180 through the lane change course 142 (Figure 3) along with a graphical presentation of some of the data recorded for this path in the evaluation rectangle 156 (Figure 3). The student's path 192 is shown bolder than the instructor's path 180 in the path display area 184. The path display area 184 shows a cone 160' and a cone 162' with a "x" symbol to denote that these cones were hit by the student 102 while driving through the course 142. In the steering graph area 182, a steering path 194 represents the position of the steering wheel 112 (Figure 1) for the ideal path, and a steering path 195 is for the student's path through the course 142. The data represented in the acceleration/braking area 186, and the velocity area 188 corresponds to the student's path 192 through the course 142. An explanation of when the summary evaluation screen 178 has just the ideal path data versus when the screen 178 has the student's path data and the ideal path will be given hereinbelow.

Figure 5 is a diagram of a video display screen showing the user's view while in replay mode (student path - eye view) through the lane change course generally indicated at 142. A similar screen display can be seen for replay of the ideal path. The view is at a section line marked 5-5 in Figure 4b. Replay mode replays the path just driven by the student, if replay student path is chosen, or by the instructor, if replay ideal path is chosen, to provide an "instant replay" capability. In the presently preferred embodiment, the steering wheel 112 (Figure 1) is turned by a motor (not shown), described in U.S. patent No. 5,044,956, in response to signals from the computer 114 corresponding to the steering wheel position when the path was originally recorded. Replay of the ideal path will, therefore, give the student the feel of when and how much the steering wheel 112 should be turned to navigate through the course. On the other hand, replay of

the student's path gives feedback to the student of what went wrong.

5 The view seen by the user 102 during replay mode is similar to the view as originally seen by the user 102 when the course was initially driven. The view shown in Figure 5 includes the set of cones 166 (Figure 4b), the city skyline 144 in the distance and the sky 146. Also shown is a velocity information box 196 containing car velocity, corresponding to the velocity information in area 188 in Figure 4b, and an
10 acceleration/braking indication box 198, which contains either the word "THROTTLE" or "BRAKE", corresponding to the information in area 186 in Figure 4b.

15 Figure 6 is a diagram of a video display screen showing a top plan view or "bird's-eye" view of the student's path through the lane change course 142 during replay mode. The top view replay is presently only used for the student's path, not the ideal path. A simulated car 200 is shown such that a "camera" is pointing downward from a point about two hundred feet above the car 200 and in line with the course. Two sets
20 of cones 160 and 162 are shown in Figure 6 with the car 200 leaving the set 160 and approaching set 162. The information box 196 is as described in conjunction with Figure 5. In Figure 6, the velocity displayed is 13 mph, and neither the gas pedal 108 nor the brake pedal 106 was depressed so, therefore, the box 198 is not displayed. As in the observer's
25 view versions of replay mode, the steering wheel 112 (Figure 1) is turned by a motor (not shown) in response to signals from the computer 114 corresponding to the steering wheel position when the path was originally recorded.

30 Thus, through the summary evaluation screen 178 (Figures 4a & 4b) and the multiple versions of the replay mode available, the student 102 (Figure 1) is provided with a means of self-improvement which is called recursive training. That is, after each pass through a particular course, the
35 student 102 tries to improve on his previous pass in comparison to the ideal path. There are multiple parameters of performance in the presently preferred driver training

system 100. The student 102 may work on a single parameter or choose to work on a multiplicity of parameters, such as braking distances, centering the vehicle on the road, and so forth. Furthermore, in other variations of the invention the route through the simulated environment may include different courses or tracks.

Figures 7, 8, 9, 10, and 11 illustrate various menu video screen displays that the user 102 will encounter while using the system 100 (Figure 1). Figures 7-10 all have a common header area 220. In Figure 7, the header area 220 shows current selections for a track line 220a, a vehicle line 220b, and a weather line 220c. As shown in Figure 7, the current track is the judgement track, the current vehicle is a police cruiser, and the current weather is day. As the user 102 uses the menu screens to make choices of track, vehicle, or weather, the header area 220 will be updated by the computer 114 to reflect the choice. A shaded line 222a at the top of a menu box 222 identifies the particular menu, which, in Figure 7, is the main menu. The select rocker switch, part of the switches 105 (Figure 1), can be pressed up or down to move a colored selection bar (not shown) corresponding to the desired choice. Then, the enter rocker switch is pressed to enter the choice into the computer 114. The lines 222c, 222d, and 222e, when selected and the enter rocker switch pressed, will cause a secondary menu to be displayed. These secondary menus are shown in Figures 8, 9, and 10. Line 222b, when selected and the enter rocker switch pressed, initiates the vehicle simulation.

Figure 8 illustrates a track menu box 230. Judgement track, line 230a, and steering track, line 230b, are the two tracks having cone courses wherein recording of parameter values is done, summary evaluation screens can be displayed, and replay mode can be executed. The other tracks are for different training purposes. For example, the pursuit tracks facilitate training in pursuit of another simulated vehicle. The main menu line 230c allows return to the main menu 222 (Figure 7).

Figure 9 illustrates a vehicle menu box 236. In the preferred embodiment, four different types of vehicles, i.e., police cruiser, sport sedan, coupe, and roadster, are presented for selection. Each vehicle has different performance characteristics which are stored in the computer 114 (Figure 1) and utilized by the model process 116 to emulate the selected vehicle. In other embodiments, different and/or additional choices could be provided for selection.

Figure 10 illustrates a weather or atmospheric effects menu box 240. In the preferred embodiment, this menu includes time-of-day conditions, i.e., day, night, dawn, and dusk, in addition to the weather conditions of fog and snow. An atmospheric effects function is performed by the computer 114 (Figure 1) to emulate the desired weather condition. In other embodiments, different and/or additional choices could be provided for selection.

Figure 11 illustrates an instruction options menu box 244 that is shown on the video display 122 (Figure 1) when the user is on one of the two cones tracks, i.e., steering or judgement tracks, and the enter rocker switch is pressed. Descriptions of the eight choices of the preferred embodiment will be given hereinbelow. In other embodiments, different and/or additional choices could be provided for selection.

Figure 12 illustrates the flow diagram for the top-level function of the control process 120 (Figure 1) called "executive_control". In one presently preferred embodiment, the control process 120 is written in the "C" language and cross-compiled using a Green Hills Software, Inc. "C" compiler available from Oasys, a division of Xel, Inc. of Waltham, Massachusetts. The control process 120 is then executed on a Motorola 68000 microprocessor located in the computer 114. However, one skilled in the art of computers will recognize that many other computer languages and computers, including pluralities of each, may be used to achieve the same result.

Prior to a start state 270, a program is downloaded from the computer 103 to the computer 114. Moving to a state 272,

the computer 114 (Figure 1) directs the video display 122 to display the main menu (Figure 7) from which the user 102 may choose to select a track from the track menu (Figure 8), a vehicle from the vehicle menu (Figure 9), and a weather condition from the weather menu (Figure 10). The user may choose to change one, two, three, or none of the main menu selections. The selection is accomplished by manipulating the select and enter rocker switches, as necessary. In some of the scenarios or programs that are downloaded from the computer 103, a series of default choices are made for the type of vehicle, track, and weather, such as, for example, track - judgement, vehicle - police cruiser, weather - day. After selections are made for track, vehicle, and weather, if desired, or the default choices are accepted, the user 102 selects the "start scenario" option and presses the enter rocker switch to signal the computer 114 to move to the next state.

Moving to a function called "init_preced" 274, the computer 114 (Figure 1) initializes observer car (the simulation vehicle) recording. The computer 114 will initiate a process by which the path followed by the observer vehicle in the upcoming scenario will be recorded. This recording can be played back at a later time to permit analysis and critique of the performance of the use during the scenario. Several initialization steps are performed in the function 274 as will be described following the description for the "executive_control" function.

The computer 114 (Figure 1) then moves to the beginning 276 of a loop 277 which only terminates when the abort rocker switch is pressed or the user 102 has crashed. The loop 277, encompassing a series of states 276 through 298, is preferably completed by the computer 114 sufficiently quickly so that position information can be displayed in real-time providing the observer car and environment with fluid movement effects on the video screen 122, the speakers 123, 124, and the low frequency speaker 830.

At a state 278, the position of the observer car is

obtained from the model process 116 (Figure 1). The model process 116 calculates the last position of the observer car based upon the user's inputs which occur asynchronously. Moving to the next state 280, the computer 114 generates output signals including sounds via the speakers 123 and 124, road feel cues via the speaker 830, vibrations on the steering wheel 112 and pulsations on the brake pedal 106 via the ABS system 900. The sounds for the observer car, for example, include skidding sounds if the observer car is losing traction on the course 142 (Figure 2).

Next, at a decision state 282, a determination is performed by the computer 114 (Figure 1) whether the user has selected or been assigned to a cone course. A cone course is a course where the user 102 will drive an automobile on a track containing cones, such as a course on either the steering track 140 or the judgement track. If a cone course has been selected or assigned, the computer 114 moves on to a "cones" function 284 wherein the user 102 is given choices on performance feedback. If a cone course was not chosen as determined by state 282, the computer 114 proceeds to state 286. At state 286, if the user 102 has selected or been assigned one of the pursuit tracks wherein the user 102 is required to pursue a specific automobile, the pursuit car, through the simulated universe, the recorded position of the pursuit car is updated. This means that the pursuit car is placed in a certain position in the graphical universe or environment 139 (Figure 2) prior to the display system of the computer 114 (Figure 1) actually updating the video display 122. Next, at a state 288, the recorded position of the observer car is updated. The observer car is placed in a certain position in the graphical universe 139. At this point in the loop 277, moving to a decision state 290, the computer 114 checks to see whether the abort rocker switch has been pressed or the simulated vehicle has crashed.

Next, moving to a "display_objects" function 292 if the abort rocker switch was not pressed or the car has not crashed, a display command is initiated to the digital signal

processor (not shown) in the computer 114 (Figure 1), such as the ADSP-2101 chip available from Analog Devices of Norwood, Massachusetts. In this function 292, display objects, such as the track, background (e.g., houses), the pursuit car (if on a pursuit track), and the observer car, are appropriately translated in the graphical universe 139 (Figure 2) according to the perspective of the user 102, for later display on the video display 122. Included in this function 292 is a call to an "atmospheric_effects" function 520 (Figure 21 described hereinbelow) to accurately simulate the track and background in various time-of-day and weather conditions.

Moving to a state 294, the instrument panel 130, including the speedometer, turn signal indicators, and various indicator lights, is updated. A separate fuel gauge (not shown) is also updated. Then, at a state 296, collision sounds, sounds associated with the observer car colliding with barriers, cones, buildings, and the like, are generated if the computer 114 determines that the simulated vehicle has collided with something. At a state 298, the video display 122 has its three-dimensional graphics display updated by a command being issued to the graphics signal processor such as, for example, the 34010 chip distributed by Texas Instruments, which can handle color filled three-dimensional graphics in real-time. Following the state 298, the computer 114 moves to state 276 to begin the next pass of the loop 277.

Returning to the decision state 290, if abort is selected or if the simulated car has crashed, the current session is terminated and the computer 114 proceeds to state 272 to begin a new session.

Referring now to Figure 13, there is illustrated the flow diagram for the "init_precord" function 274 shown in Figure 12. Beginning at a start state, the computer 114 (Figure 1) moves to a state 310 wherein the graphical universe or environment 139 (Figure 2) is initialized based on the selections made at state 272 (Figure 12) for track and weather. The computer 114 then moves to a state 312 to create the graphical object called the observer car. The observer

car object is created to be used in the student's top view replay function. Then, in a state 312, the position of the observer car object is set to the edge of the universe so that it is not seen on the video display 122 (until replay time, for example). The function 274 then returns to the "executive_control" function at a return state 316.

Referring now to Figure 14, the flow diagram for the "cones" function 284 shown in Figure 12 is illustrated. Beginning at a start state, the computer 114 (Figure 1) moves to a decision state 330 wherein it is determined whether the enter rocker switch has been pressed. If so, the computer 114 (Figure 1) moves to a state 332 and displays the instruction options menu (Figure 11) on the video display 122.

The computer 114 then checks for which option of the instruction options menu is selected by the user 102 (Figure 1) in states 334 to 354. If summary evaluation is determined to be selected at a decision state 334, the computer 114 calls the "summary_evaluation" function 336. If not, the computer 114 checks if replay ideal path is determined to be selected at a decision state 338 and if so, the computer calls the "replay_ideal_path" function 340. If not, the computer 114 checks if replay student - eye view is determined to be selected at a decision state 342 and if so, the computer calls the "replay_student_eye_view" function 344. If not, the computer 114 checks if replay student - top view is determined to be selected at a decision state 346 and if so, the computer calls the "replay_student_top_view" function 348. If not, the computer 114 checks if save ideal path is determined to be selected at a decision state 350 and if so, the computer calls the "save_ideal_path" function 352. If not, the computer 114 checks if replay speed is determined to be selected at a decision state 354 and if so, the computer 114 allows the user 102 (Figure 1) to select a replay speed. The replay speed changes from full speed (1/1) to 1/2 speed to 1/4 speed to 1/8 speed and then back to full speed in a circular queue manner by repeated pressing down on the select rocker switch. The selected replay speed is saved in the global variable

"replay_slowmo". The computer 114 then calls the "replay_speed" function 356.

5 If the replay speed choice is false at state 354, the computer 114 checks to see if the user 102 desires to change the state of the auto enable/disable flag. If so, the flag is toggled to the opposite state and the computer 114 moves to state 360. If not, the user 102 (Figure 1) has selected the exit choice of the instruction options menu and the computer 114 proceeds to state 360. The computer also proceeds to state 360 after completion of any of the functions 336, 340, 10 344, 348, 352, or 356.

At state 360, the computer 114 (Figure 1) determines if the car is stopped and the brake pedal 106 is depressed. A feature of the driver training system 100 is that the computer 114 will not automatically move from a display of the simulated graphical universe 139 (Figure 2) wherein the user 102 is driving a car to a performance evaluation display such as the summary evaluation unless the conditions of state 360 are true. These conditions help prevent the user 102 from 15 having a feeling of rapid change of environment and confusion.

20 If the conditions of state 360 are true, the computer 114 moves to a decision state 362 to determine if the auto enable/disable flag is set to the enable state. If so, the computer 114 displays the course at state 364 by calling the "summary_evaluation" function 336. Both the ideal path and the student's path (if available) are displayed. The computer 114 uses the previously run course as the student's path if it is available, i.e., it has not been purged as described in state 370 below and at least one course has been driven, and 25 if a course is not currently selected, e.g., the car is stopped before the white cones rectangle 152 (Figure 3) of a particular course. Otherwise, the computer will use the currently selected course for the student's path. The system 100 is preloaded with ideal path data for each cone course. 30 Therefore, at least the ideal path will be displayed by state 364. Following the completion of state 364, the computer 114 advances to state 360.

When either decision state 360 or 362 is false, the computer 114 (Figure 1) proceeds to state 366 and determines if the simulated car has entered the area between the two rows of white cones of rectangle 152 (Figure 3) for any of the five possible cone courses. If so, the current course is changed to that associated with the white cone area just entered by the simulated car. Next, the computer 114 purges or clears the save_point buffer. The save_point buffer (described below) is an area of memory assigned to record the data associated with the course currently being driven. The data from the previously driven course is retained in this buffer until it is purged at state 370.

Upon completion of state 370 or if the simulated car is not in the white cone area, e.g., area 152 (Figure 3), as determined by state 366, the computer 114 (Figure 1) moves to a decision state 372. At state 372, the computer determines if the car is inside the record rectangle 154 (Figure 3) of the selected course. If so, the computer 114 records the following set of data in the presently preferred embodiment at 1/5 second intervals, known as delta time, at state 374 and saves the data in the save_point buffer at state 376: (1) position of the car in three dimensional space; (2) orientation of the car in three dimensional space; (3) time associated with each data point interval; (4) position of steering wheel 112 (Figure 1); (5) current speed; (6) gas pedal 108 depressed or not (on/off flag); and (7) brake pedal 106 depressed or not (on/off flag). Three dimensional space is used for the position and orientation of the simulated car to allow for the car to roll, flip, and so forth. The time recorded starts at zero when the conditions of state 372 are true and is incremented by intervals of delta time. In the presently preferred embodiment, accurate time, known as real-time, is maintained by the computer 114 by a real-time clock. Real-time is determined by counting the interrupts generated by a four millisecond interval timer (not shown). The position of the steering wheel 112 is recorded using a linear scale of counts or units of rotation from dead center. In

other embodiments, other parameter values may be recorded and used, e.g., lateral g-force. Upon completion of state 376 or if state 372 is false, the computer 114 returns to the "executive_control" function 270 at state 378.

5 Referring now to Figure 15, the "summary_evaluation" function 336 shown in the "cones" function of Figure 14 will be described. Beginning at a start state, the computer 114 (Figure 1) moves to state 390 wherein the course for which this function 336 is to be performed is identified. The
10 course will either be the current course, as determined by state 368 (Figure 14) or the course associated with state 364 (Figure 14). Next, at state 392, the computer 114 scans an object database for cones within the evaluation rectangle 156 (Figure 3) of the selected course. At state 394, the computer
15 114 plots both regular (standing) cones and knocked-over or hit cones in a top view format on the video display 122 (Figure 1) as shown in Figure 4b.

As will described in conjunction with function 352 below, the data in the save_point buffer can be saved in a portion of
20 an ideal_path buffer. The ideal_path buffer has a section for each of the five cone courses. The ideal path data that is preloaded for each cone course is stored in the ideal_path buffer but can be overwritten as selected by the user 102 (Figure 1). At state 396, data is retrieved from the
25 ideal_path buffer for the selected course and from the save_point buffer (if available) for each delta time interval recorded at state 374 (Figure 14). The following parameter values are retrieved for this function 336: position of steering wheel 112 (Figure 1), position of car, velocity,
30 status of brake pedal 106, and status of gas pedal 108. The retrieved values are then plotted at state 398 by the computer 114 on the video display 122 as shown by the example of Figure 4b. The display has an implied distance scale that is proportional to the course length, thus, a longer course means
35 a more condensed display. Only data points within the evaluation rectangle 156 are plotted. The velocity values are displayed at intervals determined by the computer 114 such

that the display is easy to read. Upon completion of state 398, the computer returns at state 400 to the "cones" function 284 of Figure 14.

Referring now to Figure 16, the "replay_ideal_path" function 340 shown in the "cones" function of Figure 14 will be described. This function 340 performs an "instant-replay" feature of the ideal path from a viewpoint inside the car, along with controlling the steering wheel 112 (Figure 1) to emulate the motions of the wheel 112 when the course was initially recorded. Beginning at a start state, the computer 114 (Figure 1) moves to state 410 wherein the system real-time clock is cleared to coincide with the start of recorded data (delta time = time zero) for the selected course. Then, at a decision state 412, the computer 114 determines if the real-time value equals a delta time value of a recorded data point. For example, if the real-time value is 3/5 second after time zero, a delta time interval would match (three times 1/5 second) and the computer 114 proceeds to state 414.

At state 414, the computer 114 retrieves the data associated with the delta time interval of a recorded data point in the ideal_path buffer for the selected course. The data retrieved for this function 340 includes: the position of the car, the orientation of the car, and the position of the steering wheel. The retrieved values are then captured at state 416 in a global variable "camodb" (camera object database).

In the presently preferred embodiment, the loop of function 340 is executed approximately ten to thirty times per second. Because data is recorded at 1/5 second intervals, if a full speed replay is desired, interpolation between data points must be done. (Replay speeds of 1/2, 1/4, or 1/8 normal speed replay are available as will be described below.) At full speed, therefore, approximately 5 to 25 interpolations must be done. At state 412, if the real-time clock value did not match a delta time interval, e.g., the real time clock was at 3/10 second and full speed replay is selected, the computer 114 (Figure 1) moves to state 418. At state 418, the computer

does a linear interpolation between the two nearest recorded data values, as determined by the real-time clock value, for the following parameters: the position of the car, the orientation of the car, and the position of the steering wheel. The newly created values are then captured at state 420 in the global variable "camodb".

Following completion of either state 416 or 420, the computer 114 (Figure 1) moves to state 422 and updates a global variable "replay_force" with the data for the position of the steering wheel 112 (Figure 1) from the results of state 414 or 418. Replay_force is used at state 424 by a steering process to asynchronously force a steering controller of the steering wheel 112 through an Interrupt Service Routine (ISR).

As the steering wheel 112 (Figure 1) is being controlled through state 424, the computer 114 (Figure 1) executes "display_objects" function 292 wherein a display command is initiated to the ADSP. Display objects, such as the track, and background, are appropriately translated in the graphical universe 139 (Figure 2) according to the perspective of the user 102, for later display on the video display 122 (Figure 1). Included in this function 292 is a call to the "atmospheric_effects" function 520 (Figure 21) to accurately simulate the track and background in various time-of-day and weather conditions. At a state 428, the video display 122 has its three-dimensional graphics display updated by a command issued to the GSP. The computer 114 then moves to a decision state 430 and determines if there are more data points in the ideal_path buffer for the selected course. If so, the computer 114 loops back to the decision state 412 where a new value of the real-time clock is checked. When all data points in the ideal_path buffer for the selected course have been used at state 430, the computer 114 returns at state 432 to the "cones" function of Figure 14.

The "replay_student_eye_view" function 344 shown in Figure 14 is very similar to the "replay_ideal_path" function 340 just described. The difference is that the data is retrieved from the save_point buffer rather than the

ideal_path buffer.

Referring now to Figure 17, the "replay_student_top_view" function 348 shown in the "cones" function of Figure 14 will be described. This function 348 performs an "instant-replay" feature of the student's path from a simulated viewpoint two hundred (200) feet above the car, along with controlling the steering wheel 112 (Figure 1) to emulate the motions of the wheel 112 when the course was initially recorded. This function 348 is similar to the "replay_ideal_path" function 340 and, therefore, only the states different from those in function 340 will be described.

States 440 and 442 perform the same task as states 410 and 412 of function 340 (Figure 16). States 444 and 448 are similar to states 414 and 418 of function 340 except that the data is retrieved from the save_point buffer in function 348 rather than the ideal_path buffer in function 340. States 446 and 450 are similar to states 416 and 420 of function 340 except that the values for the position and orientation of the car are saved in a global variable "my_object" in function 348 rather than the global variable "camodb" in function 340. States 452 and 454 perform the same task as states 422 and 424 of function 340.

The major difference between the two functions 340 (Figure 16) and 348 is at state 456 of function 348 wherein the view seen on the video display 122 (Figure 1) is changed from inside the simulated car looking forward to an overhead view looking down at the car and moving with the car. The camera is set to be at an apparent height of two hundred (200) feet above the simulated car and oriented to look downward and in line with the course. The camera moves with the car to produce a view that is directly over the car as the car moves through the course. At state 458, the new camera view values from state 456 are captured in the global variable "camodb". At the "display_objects" function 292, the objects displayed from the "bird's-eye" perspective include the track and a representation of the observer car. The observer car is only displayed in the "replay_student_top_view" function 348.

States 462 performs the same task as state 428 of function 340. Decision state 464 is similar to decision state 430 of function 340 except that the buffer checked is the save_point buffer at state 464 rather than the ideal_path buffer at state 430. At state 466, the computer 114 then returns to the "cones" function 284.

Referring now to Figure 18, the "save_ideal_path" function 352 shown in the "cones" function of Figure 14 will be described. This function 352 saves the data associated with the course that was just driven as the new ideal path for that course. Beginning at a start state, the computer 114 (Figure 1) moves to state 470 wherein the data in the save_point buffer is retrieved. Moving to state 472, the computer 114 copies the retrieved data into the ideal_path buffer corresponding to the course for which the data was recorded. Then, at state 474, the computer 114 returns to the "cones" function 284 (Figure 14).

Referring to Figure 19, the "replay_speed" function 356 shown in the "cones" function of Figure 14 will be described. This function 356 sets up a subsequent call to one of the replay functions, but with a slow-down factor such that the replay is slow enough for the user 102 (Figure 1) to observe and learn more. The function 356 itself does not start a replay. Beginning at a start state, the computer 114 (Figure 1) moves to state 480 wherein the global variable "replay_slowmo", described in conjunction with the "cones" function (Figure 14), is retrieved. Moving to a decision state 482, the computer 114 determines if the replay speed selected is 1/2. If so, the delta time is multiplied by two. What this means is that, during replay mode, instead of five actual data points available per one second with a delta time interval of 1/5 second for full speed, there will be five actual data points available per two seconds of replay time with a delta time interval of 2/5 second for 1/2 speed. Thus, five additional interpolations (to create new intermediate values) will be done for each two second interval by one of the replay functions 340, 344, or 348 (Figure 14) to account

for the reduced number of actual data points available.

If the replay speed selected is not 1/2 as determined at decision state 482, the computer 114 proceeds to state 486 to determine if the selected speed is 1/4. If so, the delta time is multiplied by four. The delta time interval becomes 4/5 second, and five actual data points will be available per each four seconds of replay time. If the replay speed selected is not 1/4 as determined at decision state 486, the computer 114 proceeds to state 490 to determine if the selected speed is 1/8. If so, the delta time is multiplied by eight. The delta time interval becomes 8/5 second, and five actual data points will be available per each eight seconds of replay time. If the replay speed selected is not 1/8 as determined at decision state 482, the implied speed is full speed, and therefore, delta time is not multiplied. The computer 114 (Figure 1) proceeds to state 494 and returns to the "cones" function 284 (Figure 14).

The approximation of weather, time of day (e.g., dawn, dusk, night), and atmospheric conditions or hazing aspect of the present invention is demonstrated in the screen displays shown in Figures 20a, 20b, and 20c. Figure 20a is a diagram of a video display screen showing a view as the user 102 (Figure 1) approaches a mountain range 502 along a simulated roadway 504. Figure 20a also shows a sky 508 and a ground 509. Figure 20b shows the same view as Figure 20a, but with a layer of haze 506. The haze 506 could be the result of fog, smog, smoke, or any other similar atmospheric condition. In Figure 20b, the haze 506 is of a thickness that the mountain range 502 in the background is partially visible. This condition may represent dusk or dawn. In Figure 20c, the condition simulated is fog 506', wherein the hazing is so thick as to obscure the background mountain range 502' (Figure 20b). As the user 102 (Figure 1) approaches an object, e.g., a building or a road sign, as shown in Figure 20c, along the roadway 504', the haze 506' lightens and gradually the object (in Figure 20c) changes colors due to the optical distortion caused by particles in the air reflecting and blocking light.

A sequence similar to that of the previous sentence occurs for the mountain range 502 (in Figure 20b). Also, brightness is affected by haze. For example, in Figure 20c, a first building 510 is more distinct and brighter than a second building 512 that is at a greater distance from the position of the simulated car. It should be understood that Figures 20a,b,c only demonstrate the effect of hazing in the horizontal dimension while hazing in the vertical dimension, though not shown, is also included in the present invention.

Referring generally to Figures 20a,b,c, the haze 506 distorts colors according to the type of atmospheric condition being simulated. For instance, in the presently preferred embodiment, the following conditions and color tones are displayed in the graphical universe 139: night - black, fog - grey, dusk - violets, dawn - yellows, day - standard or default colors, and snow - white.

In the hazing process of the present invention, sky 508 and ground 509 are treated differently from other objects in the graphical universe 139. Of course, the types of atmospheric conditions or hazes available to the user 102 (Figure 1) will be preselected by an animator. In the presently preferred vehicle simulator embodiment of the invention, six conditions are presently provided and are selectable by the user 102. These conditions are shown in Figure 10 as a menu display of the driver training system 100. So that processing time is conserved by the computer 114 (Figure 1), certain other assumptions of the present embodiment are that the haze 506 has a uniform consistency, and that all points of a polygon are treated as the same color even though individual points may be different distances from the viewpoint or camera position looking into the graphical universe 139.

Figure 21 shows a flowchart of a portion of the approximation of atmospheric conditions or "atmospheric_effects" function 520 of the present invention. The function 520 is called by the "display_objects" function 292 of the "executive_control" function 120 (Figure 12), the

"replay_ideal_path" function 340 (Figure 16), and the "replay_student_top_view" function 348 (Figure 17). It is important to note that the "atmospheric_effects" function 520 is not embodied in any one function in the control process 120 (Figure 1) but instead is distributed among various states and functions of the control process 120. Thus, the flow diagram of Figure 21 is only a logical representation of a collection of functions. The 68000 microprocessor, the ADSP, and the GSP each has associated computer source code for the "atmospheric_effects" function 520.

With reference to the hazing aspect of the present invention, of particular interest to understanding the well-known function performed by the control process 120 is section 16.2 entitled "Diffuse Reflection and Ambient Light" (pp. 575-577) of the textbook Fundamentals of Interactive Computer Graphics by J.D. Foley and A. Van Dam, this section being hereby incorporated by reference.

The "atmospheric_effects" function 520 makes the following changes to parameters, or characteristics, of the graphical universe 139 (Figure 20a): (1) sky color - a function of thickness of the haze; (2) ground color - similar to sky color; (3) dimval - a preselected parameter that determines the minimum distance before the haze begins to affect colors; (4) kval - a preselected parameter that determines how quickly colors change in haze; (5) sun1, sun2 - preselected positions and intensities of two light sources; and (6) color palettes - preselected hues and intensities associated with each polygon that determine how colors change in haze.

The sky and ground colors are changed dynamically at state 546 of function 520. The remaining above-listed parameters are set in the initialize universe states 522 and 524. The multiple light sources, or suns (sun1 and sun2), are used to provide greater depth to the polygonal images. For instance, in the case of a single sun, if an object of uniform color faces the user and there is a corner where two faces meet, both faces would appear to have the same color and thus

z and dimval. If z is greater than dimval, the polygon is completely obscured by the haze and no further processing (dithering) is performed for this polygon. The function 520 continues to a decision state 544 to check if more polygons exist. If, however, z is less than dimval, the polygon is partially visible through the haze and function 520 moves to state 534.

At state 534, the shade value for the polygon is

would appear joined in a flat plane. However, if one sun is directing 90% of the total light intensity at a first angle and the other sun is directing 10% of the total light intensity from a second angle, then one face of the object has a slightly different shade of color than the other. Resolving the issue of depth becomes especially important when there is a limited number of colors to choose from in any given palette, which will likely be the case for most common video systems.

10 In the presently preferred system 100 (Figure 1A) shown

determined. This value is determined by performing the dot products of the sun vectors, $S_i = (x_i, y_i, z_i)$ and the normal, $N = (x, y, z)$, to the polygonal plane. Each dot product is a scalar having a magnitude depending on the angle subtended between the two vectors and the magnitude of the sun vector. Thus, if two vectors are perpendicular, their dot product will be zero, indicating one-half intensity of the polygon color. On the other hand, if the two vectors point toward one another such that maximum sunlight is received on the polygonal plane, (i.e., $S_i = -N$), the predetermined natural color of the polygon will be seen by the observer. Then state 534 sums the components of the dot products (in the present embodiment there are two suns, sun1 and sun2). A translation factor is added to the sum to produce a range of positive values called $A = (0, M)$ where M is the worst case sum of the dot products after scaling. In general, each sun vector has a magnitude (intensity) that is equal to 1.0 so that, assuming that the suns are pointing in the same direction, the maximum possible range before scaling is $(-2.0, 2.0)$. After scaling, the range is scaled so that the magnitude of A will always be $(0, 4.0)$.

The "atmospheric_effects" function 520 then proceeds to state 536 where the colors of the dither pattern for the polygon are determined. The dither colors are defined in a dither lookup table that is indexed by haze value and shade value. Each entry in the dither lookup table contains offsets into the polygon palette for the two colors, $X0$ and $X1$, to be used in the dither pattern. In the present embodiment, each polygon uses 16 colors in the palette for each polygon; thus, $X0$ and $X1$ have values between 0 and 15.

The "atmospheric_effects" function 520 the proceeds to state 538 where the offsets for the two dither colors are added to the base color. The base color, B , of a polygon specifies which group of 16 colors to use. In a palette of 256 colors, there is a possibility of 16 groups of colors to choose from. Thus the base color for a polygon is in the range 0 to 15. The two dither colors for a polygon, $C0$ and $C1$, are determined as follows:

performed by the ADSP and GSP of the computer 114 (Figure 1).

Thus, moving to a loop state 526, the "atmospheric_effects" function 520 begins the set of states that will select colors for polygons according to the
5 preselected thickness of haze as determined by dimval and kval. At the following state, state 528, the "atmospheric_effects" function 520 selects a polygon for coloring. As noted previously, objects in the graphical
10 universe 139 (Figure 20a), e.g., buildings or signs, are formed from polygons. It is polygons from these objects which are selected for coloring.

The "atmospheric_effects" function 520 moves to the state 530 wherein the function 520 calculates the distance z , between the camera and the selected polygon. The farthest
15 vertex of the polygon is chosen as the polygon reference point for the distance z , but any point on the polygon could be chosen. State 530 then calculates the haze value from the distance z as follows:

$$\text{haze value} = (z * \text{kval}) / \text{dimval}$$

20 where

z is the distance between the camera position and the polygon;

kval is a constant; and

dimval is the distance for full hazing.

25 In a floating point application of the "atmospheric_effects" function 520, kval is preferably set to the haze range. In an integer application, however, kval is chosen so as to provide sufficient range to cover the entire haze range.

Then at a decision state 532, the function 520 compares
30 z and dimval. If z is greater than dimval, the polygon is completely obscured by the haze and no further processing (dithering) is performed for this polygon. The function 520 continues to a decision state 544 to check if more polygons exist. If, however, z is less than dimval, the polygon is
35 partially visible through the haze and function 520 moves to state 534.

At state 534, the shade value for the polygon is

determined. This value is determined by performing the dot products of the sun vectors, $S_i=(x_i,y_i,z_i)$ and the normal, $N=(x,y,z)$, to the polygonal plane. Each dot product is a scalar having a magnitude depending on the angle subtended between the two vectors and the magnitude of the sun vector. Thus, if two vectors are perpendicular, their dot product will be zero, indicating one-half intensity of the polygon color. On the other hand, if the two vectors point toward one another such that maximum sunlight is received on the polygonal plane, (i.e., $S_i=-N$), the predetermined natural color of the polygon will be seen by the observer. Then state 534 sums the components of the dot products (in the present embodiment there are two suns, sun1 and sun2). A translation factor is added to the sum to produce a range of positive values called $A = (0,M)$ where M is the worst case sum of the dot products after scaling. In general, each sun vector has a magnitude (intensity) that is equal to 1.0 so that, assuming that the suns are pointing in the same direction, the maximum possible range before scaling is $(-2.0,2.0)$. After scaling, the range is scaled so that the magnitude of A will always be $(0,4.0)$.

The "atmospheric_effects" function 520 then proceeds to state 536 where the colors of the dither pattern for the polygon are determined. The dither colors are defined in a dither lookup table that is indexed by haze value and shade value. Each entry in the dither lookup table contains offsets into the polygon palette for the two colors, X0 and X1, to be used in the dither pattern. In the present embodiment, each polygon uses 16 colors in the palette for each polygon; thus, X0 and X1 have values between 0 and 15.

The "atmospheric_effects" function 520 then proceeds to state 538 where the offsets for the two dither colors are added to the base color. The base color, B, of a polygon specifies which group of 16 colors to use. In a palette of 256 colors, there is a possibility of 16 groups of colors to choose from. Thus the base color for a polygon is in the range 0 to 15. The two dither colors for a polygon, C0 and C1, are determined as follows:

$$C0 = (B * 16) + X0$$

$$C1 = (B * 16) + X1$$

Next, state 540 determines the dither pattern based on the position of the polygon. The dither pattern employed in the present embodiment uses a 2-color 2 x 2 dither pattern arranged in an "X" pattern as follows:

<u>pattern 1</u>	OR	<u>pattern 2</u>
C0 C1		C1 C0
C1 C0		C0 C1

To avoid dither pattern interference at polygon edges, dither patterns need to be aligned to the vertical position on the screen. Thus, state 540 selects pattern 1 if the polygon starts on an even scan line and pattern 2 if on an odd scan line. Thereafter, the control process 120 (Figure 1), employing the GSP, draws the polygon on the video display 122 as shown at state 542 using the dither pattern calculated in state 540. Next, the ADSP determines whether there are more object polygons to color and display at state 544. If there are more polygons, then the "atmospheric_effects" function 520 continues by moving to loop state 526. Otherwise, if all object polygons have been drawn, then the function 520 proceeds to state 546.

At state 546 after a frame change initiated by the GSP, the function 520 sets the colors palettes for the sky 508 (Figure 20a) and ground 509. For instance, the colors of the sky 508 are chosen such that the sky is the color of the haze, e.g., gray for fog and black for night. Similarly for the ground 509, the color palette is changed according to the color and density of the haze.

Although the following discussion refers to the coloring of the ground 509, it should be understood that a similar procedure is applied to change the color palette of the sky 508. The ground 509 (Figure 20a) consists of many polygons, each corresponding to a given distance from the camera. As the camera moves closer to these polygons, they gradually appear out of the haze. For ground colors a set of fifteen colors are presently preferred ranging between colors 0 and 14

as follows: color 14 - the color of a polygon beyond the range of maximum visibility and color 0 - the color of a polygon without any atmospheric discoloration. Also, the horizon is segmented into fifteen polygons. The larger the number of colors and polygons the better the approximation. However, as these numbers increase, the computation becomes more complex. Hazing of the horizon image is performed to match the current dimming distance (dimval).

As an example, the hazing conditions are set for fog with a 140 ft. visibility. Each polygon is spaced 10 ft. apart (140 ft./14) with polygon 0 being 0 ft. from a camera located at the lowest point of the ground 509 and polygon 14 being 140 ft. from the same camera position. Then assume that the vehicle has driven to the top of a 50 ft. rise. Thus, polygon 0 is 50 ft. from the camera, polygon 1 is 60 ft. from the camera, and so on. To determine the color for any polygon, polygon 0, for example, the "atmospheric_effects" function takes the distance between the polygon and the camera, 50 ft., and linearly interpolates between the colors of the original range. For example, to set the colors of the color palette associated with the ground 509, polygon 0 would be 50/140 (35.7%) between the ground color and the fog color, polygon 1 would be 60/140 (42.8%), etc. Polygons more distant than the visibility distance, 140 ft. in this example, would be obscured by the fog and be 100% fog color.

Changing the maximum visibility means that the distance between the polygons is different. For example, if the visibility is 350 ft., then each polygon is spaced 25 ft. apart (350 ft./14). With the vehicle at the top of a 50 ft. rise, polygon 1 would then be the color 75/350 (21.4%) between ground color and fog color.

The instrument panel 130 of the system 100, as shown in Figure 22, includes a speedometer 602, a transmission gear indicator display area 604, a transmission gear indicator 606, an indicator and warning light area 608. Several input devices of the system 100, including the turn signal lever 104, the automatic transmission or shift lever 110, and the

steering wheel 112, are also shown. The speedometer 602 and indicators become active when the user 102 (Figure 1) "starts" the simulated vehicle. The speedometer 602 provides a measurement of velocity. The gear indicator 606 visually displays the position of the shift lever 110 upon the gear indicator display area 604. The indicator and warning light area 608 includes the following designators (left to right): left turn signal 608a, temperature, battery, seat belt, brake, ABS, oil pressure, high beam (headlights), emergency flasher, and right turn signal 608b. Of significance to this discussion is the turn signal lever 104 mounted on a steering column housing 610.

Referring now to Figure 23, an assembly 612 for the turn signal lever 104 mounted on the steering column housing 610 will be described. The assembly 612 is contained within the housing 610. The lever 104 has three positions: a center or neutral position indicated by the solid lines, a right turn position 104' indicated by the dashed lines, and a left turn position (not shown). When the user 102 (Figure 1) desires to make a right turn, he will press the lever 104 upward until a detent position is reached, which activates the right turn signal 608b (Figure 22). Then, usually after a brief moment of driving straight, the user 102 begins turning the steering wheel 112 (Figure 22) in a clockwise direction from a center position. The center position is the position of the steering wheel 112 when the simulated car is moving in a straight-ahead path. The assembly 612 maintains the active state of the right turn signal 608b into the turn. After the apex of the corner has been reached, the steering wheel 112 is turned in a counterclockwise direction. While the steering wheel 112 is returning toward the center position, the lever 104 returns to the center position and the right turn signal 608b shuts off.

The turn signal lever 104 is held by a retainer plate 614 mounted on a frame 618, which turn about a pivot point 616. A right turn plunger 619 is mounted in a bore in the frame 618 and is held in position by a spring (not shown) in

the bore. A center detent 620, a right detent 621 (dashed lines), and a left detent 622 are shown on the retainer plate 614. The right and left detents are used to hold the position of the lever 104 from the center detent position.

5 In a nominal centered position for the lever 104, two balls biased by an intermediary spring (not shown), and positioned longitudinally in the assembly 612, engage the center detent or hole 620. However, upon movement of the lever 104 into its righthand turn position 104', the spring is
10 compressed and the upper ball thereby disengages the center detent 620. The retainer 614 is then allowed to pivot until the upper ball is forced by the spring into the right detent 621.

 A right turn microswitch 624 connects to the computer 114
15 (Figure 1) via signal wires (not shown). When the lever 104 is pressed upward to a position 104', the frame 618 rotates clockwise around the pivot point 616 and depresses a micro-plunger of the microswitch 624 until a hard stop 626 is reached. New right turn positions of the frame 618' and the
20 plunger 619' are indicated by dashed lines. The turn signal lever 104 is held at the position 104' by the right detent 621. The microswitch 624 sends a signal to inform the control process 120 (Figure 1) that a right turn is taking place. The control process 120 then sends a signal to the instrument
25 panel 130 (Figure 1) activating the right turn signal 608b (Figure 22).

 As the user 102 (Figure 1) begins turning the steering wheel 112 (Figure 22) clockwise for a right turn, a cancel pin 630 also turns with the steering wheel in a hub area 632. A
30 rotation 634 of the cancel pin 630 moves the plunger 619 in the bore against the spring, but does not affect the position of the frame 618'. After the cancel pin 630 passes by the plunger 619 in its temporary position pressed against the spring, the plunger returns to its dashed line position 619'.
35 The cancel pin 630 continues its rotation until, for example, a twelve o'clock position is attained at the apex of the right turn. Then, as the steering wheel 112 is turned in a

counterclockwise direction to straighten the travel of the simulated car, a rotation 640 causes the cancel pin 630 to press against the side of the plunger 619 at position 619'. This pressure on the plunger 619 causes the frame 618 to turn
5 counterclockwise about the pivot point 616 which causes the lever 104 to return to the center position. The micro-plunger on the microswitch 624 is thereby released to deactivate the right turn signal 608b (Figure 22) via a signal sent to the computer 114 (Figure 1). A similar microswitch, hard
10 stop, and plunger (not labelled) to those discussed above are symmetrically positioned in the assembly 612 for making a left turn.

Figure 24 is a side elevational diagram of one preferred embodiment of a seat and low frequency speaker assembly 800
15 shown in partial cross-section. The purpose of the assembly 800 is to provide the user 102 (Figure 1) with meaningful and realistic road feel cues. The assembly 800 includes a housing such as a seat 802, preferably made of a light weight plastic or upholstered wood, upon which the user 102 will sit while
20 operating the system. The seat 802 is movably mounted on a housing 804, preferably made of thick metal, containing a seat adjust mechanism. The seat adjust mechanism can be of any type known in the art which permits the user 102 to adjust the seat 802 into a preferred position relative to the driving
25 controls (Figure 1). Seat adjustment is accomplished by the user 102 manipulating a seat adjust control 806.

The seat adjust mechanism housing 804 is attached to the top of a mounting post, generally indicated by the reference numeral 808. In this preferred embodiment, the mounting post
30 808 is cylindrical and preferably made of a solid material such as stainless steel, with a top portion 809 and a bottom portion 810, the bottom portion 810 having a smaller diameter than the top portion 809. A cylindrical bearing 812 is mounted flush on the bottom portion 810 of the mounting post
35 808.

The bottom portion 810 of the mounting post 808 extends through a mounting hole 814 (shown in Figure 25) in a swivel

base 816. The mounting hole 814 is preferably 4 inches in diameter which is slightly larger than the outer diameter of the bottom portion 810 of the mounting post 808. The bearing 812 is mounted on the bottom portion 810 of the mounting post 808 such that when the bottom portion 810 extends through the mounting hole 814, the upper surface of the bearing 812 will be positioned between the upper portion 809 and the upper surface of the swivel base 816. The bearing 812 can be of any type known in the art which will facilitate swiveling the seat 802. The swivel base 816 is preferably made of stainless steel and is flushly mounted on top of a seat mounting plate 820 and is primarily secured thereto by four screws 822 (two shown) which extend through the seat mounting plate 820 into a semi-rigid diaphragm 824.

A securing member 826 is attached to the bottom portion 810 of the mounting post 808 underneath the swivel plate 816, such that the securing member 826 prevents the mounting post 808 from being lifted out of the mounting hole 814 while still permitting the seat 802 to swivel. A person skilled in the art can appreciate that the securing member 826 can be comprised of a nut and lock washer used in combination with threads on the bottom portion 810 of the mounting post 808 or any other combination which secures the mounting post 808 in the described fashion while still permitting the seat 802 to be swiveled.

The swivel plate 816 is attached to the seat mounting plate 820, which is preferably a 16 inch by 18.75 inch piece of 3/4 inch thick plywood with beveled edges. The seat mounting plate 820 is further attached to the semi-rigid diaphragm 824. The semi-rigid diaphragm 824 is preferably a 29.80 inch by 35.50 inch piece of 1/2 inch or 3/8 inch thick plywood, the top of which is covered by corrugated rubber matting 825 (shown in Figure 25) suitable for providing secure footing for the user 102. The semi-rigid diaphragm 824 must be sufficiently flexible so that it can vibrate in response to changes in air pressure induced by the low frequency audio speaker 830 positioned on an adjacent enclosure 828. The

operation of the speaker 830 and the enclosure 828 will be discussed in greater detail below.

5 Connected to the bottom side of the semi-rigid diaphragm 824, at its outside edges, are four vertical support members 832 (two shown). The vertical support members 832, are preferably made from 3/4 inch thick particle board, and they are connected to the semi-rigid diaphragm 824 along its outside perimeter so that they extend perpendicularly downward. Connected to the bottom surfaces of the vertical support members 832 is a horizontal support member 834, 10 preferably made from 3/4 inch thick particle board, which serves as a base plate for the assembly 800. The length and width dimensions of the horizontal support member 834 are substantially identical to the dimensions of the semi-rigid diaphragm 824 such that when the semi-rigid diaphragm 824, the vertical support members 832 and the horizontal support member 834 are assembled, they form a rectangular box-like structure. Also mounted to the bottom side of the semi-rigid diaphragm 824, parallel to, and inset approximately one inch from each 20 of its outside edges are four cleats 836 (two shown). The four cleats 836 preferably consist of lengths of mahogany wood with a 3/4 inch square cross section. Where the cleats 836 intersect near the corners of the semi-rigid diagram 824, they are preferably joined to each other in a substantially air-tight fashion. 25

Attached to the bottom side of the cleats 836, in a substantially air-tight fashion, is a speaker member 840. The speaker member 840 is preferably a 27.80 inch by 33.50 inch rectangular piece of 3/4 inch thick particle board. The speaker member 840 further contains a circular hole 842 with approximately a 7 inch diameter. The speaker 830 is mounted to the underside of the speaker member 840, preferably in a substantially air-tight fashion, so that the diaphragm of the speaker 830 is substantially centered about the hole 842 and is exposed to the air within the enclosure 828. The enclosure 828 is thereby formed by the semi-rigid diaphragm 824, the cleats 836, the speaker member 840, the speaker 830, and the 35

swivel base 816. Preferably, the enclosure 828 is air-tight, however, perfect air-tight integrity is not a requirement for the operation of the assembly 800. In this presently preferred embodiment, the speaker 830 is a model QUAM -
5 NICHOLS, eight inch, 8 Ohm, 50 Watt two terminal woofer speaker part number 92-9846.

Figure 25 is a top plan view of the base portion of the seat and speaker assembly, taken along line 25-25 of Figure 24. Figure 25 selectively shows the relative mounting
10 locations and sizes of some of the members which comprise the base containing the speaker 830 and the enclosure 828 of the presently preferred embodiment. For purpose of clarity in the description below, two direction arrows 844 and 846 are shown in Figure 25. The mounting hole 814 in the plate 820 is
15 preferably offset from the center of the plate 820 by approximately 4 inches in direction of the arrow 846 and approximately 3 inches in the direction of arrow 844. The mounting post 808 (shown in Figure 24), extends perpendicularly outward from hole 814 and is preferably
20 coupled to the seat adjust mechanism housing 804 (shown in Figure 24) offset from the center of the housing 804 in the same direction as the arrow 844 by the same distance as the mounting hole 814 is offset in the direction of the arrow 844 from the center of the plate 820.

25 When the seat 802 is oriented in its nominal operational position, facing in the opposite direction as the arrow 846, as shown in Figure 24, the seat 802 will be located such that it is centered over the seat mounting plate 820 in the direction of the arrow 844 while being offset approximately 4
30 inches from being centered over the plate 820 in the direction of the arrow 846. Positioning the seat 802 in this fashion permits easier access to the seat 802 by the user 102 as the seat 802 can be swiveled so when the seat 802 faces in the direction of the arrow 844, the edge of the seat 802 will
35 preferably extend beyond the edge of the semi-rigid diaphragm 824. Figure 25 also shows the locations of four holes 823 for the four screws 822 which secure the swivel plate 816 (Figure

24) to the seat mounting plate 820 and to the semi-rigid diaphragm 824. The speaker hole 842 is located substantially at the center of the speaker member 840 (Figure 24). As shown in Figure 25, the hole 842 is then located in the speaker member 840 underneath and at the approximate center of the semi-rigid diaphragm 824. The top surface of the semi-rigid diaphragm 824 is preferably covered by the corrugated rubber matting 825, shown in part in Figure 25. This matting 825 is preferably fixedly attached to the semi-rigid diaphragm 824 through the use of tacks or glue. Also shown in Figure 25 are the cleats 836, mounted underneath the semi-rigid diaphragm 824, which are also shown to meet and join each other at their ends.

The basic operation of the assembly 800, will now be explained by referring again to Figure 1. The control process 120 receives input from the model process 118 indicating that an event, e.g., collision with an object, engine vibration and so forth is occurring. In response, the control process 120 accesses a digital representation of a signal in a wave table (not shown) stored in one of the RAMs of the computer 114. The wave table stores a well-known digital representation of the frequency content, the amplitude and the duration of the signals corresponding to various events, e.g., collision with specific objects, engine noise. Once a digital representation is accessed, the control process 120 then reproduces the digital representation and causes its translation into an analog signal representative of the specific event which is then fed to the low pass filter 854.

The filter 854 is a low pass filter with a frequency response of 20 to 80 Hertz (Hz), hence, only signals with a frequency content below 80 Hz will be passed by the filter 854 to the amplifier 850. The amplifier 850 is a 28 Watt power amplifier capable of producing a 24-volt, peak-to-peak output signal at maximum gain. Hence, the amplifier 850 increases the amplitude of the low frequency signal it receives from the low pass filter 854 and feeds this amplified low frequency signal to the relay 852.

The relay 852 is designed to protect the speaker 830 from damage caused by voltage spikes generated by either powering up or powering down the system 100. As is understood in the art, oftentimes when electronic equipment is in a period of power transition, transient voltage spikes are generated which, if transmitted to audio speakers of a type similar to speaker 830, can result in damage to the speakers. Even if these transients do not damage the speaker 830 they may unsettle the user 102 sitting in the seat 802. Consequently, the relay 852 is connected to the control circuit 856, described below, which will disconnect the speaker 830 from the electrical circuitry of the system 100 during periods of power transition.

Referring now to Figures 1, 24 and 25, when the system 100 is not in a period of power transition, the relay 852 will send the high amplitude, low frequency signal received from the amplifier 850 to the speaker 830. The diaphragm of the speaker 830 will then vibrate in response to the high amplitude, low frequency signal, thereby displacing the air within the enclosure 828. This displacement of the air within the enclosure 828 causes the semi-rigid diaphragm 824, which shares common structural components with the enclosure 828, to bounce or vibrate. The vibration of the semi-rigid diaphragm 824 is then communicated through the seat mounting plate 820 and the seat mounting post 808 to the seat 802 and then to the user 102. In this fashion, events such as engine vibration, hitting an object, and so forth can be realistically represented to the user 102 of the simulation system 100.

For example, to simulate the feel of hitting a cone while driving the simulated car on the course 142 shown in Figure 2, the control process 120 retrieves a wave sample of the sound from the wave table (not shown) and feeds the equivalent analog signal, having a sharp low frequency peak to the filter 854. The filter 854 passes the low frequency content (below 80 Hz) of the signal to the amplifier 850. The amplifier 850 increases the amplitude of the signal and passes it to the relay 852. This high amplitude signal will then be sent to

the speaker 830 if the system 100 is not in a period of power transition. The speaker 830 communicates a high excursion pulse through to the air within the enclosure 828 by vibrating the diaphragm of the speaker 830. The resulting displacement and consequent compression of air within the enclosure 828 is transmitted to the semi-rigid diaphragm 824 and ultimately to the user 102 sitting on the seat 802. The user 102 will then experience a quick jolt to simulate the feel of hitting the cone as the speaker diaphragm moves the air in the enclosure 828.

The control process 120 can cause different samples of sound stored in the wave table to be transmitted, in the above-described fashion, to the user 102 for a single event. The low frequency signal generated by the control process 120 for a cone collision may have a duration in the range of 100 milliseconds to one second. Other signals, such as those defining engine vibration may have longer duration. By increasing the number of sound samples stored in the wave table, many other road feel cues may be utilized by the system 100. During the same event, the control process provides independent signals to the speakers 123 and 124 which are indicative of engine noises, cone collisions and so forth.

The relay control circuit 856 is more fully described by reference to Figure 26. The relay control circuit 856 is designed to turn the relay 852 off during periods of power transition, e.g., when powering up and when powering down the system 100. The circuit 856 is designed so that when the actual voltage for the system 100 falls below its normal input voltage, preferably 14 VDC, the relay 852 will disconnect the input to the speaker 830 from the output of the amplifier 850. A 12 VAC output signal of a transformer (not shown) is rectified in a well-known manner to produce the 14 VDC signal.

The operation of the circuit 856, shown in Figure 26 will now be described. When the system 100 is turned on, the AC voltage from the transformer ($V_{\text{transformer}}$) is input to a diode 857, this voltage then begins to charge a capacitor 860 coupled to the non-inverting input (+) of a comparator 864.

Simultaneously, a capacitor 863, which is connected to the inverting (-) input of the comparator 864 is charged by the normal input voltage or reference voltage (V_{ref}), preferably 14 VDC, through a resistor 862. A capacitor 870, which is
5 connected to the non-inverting (+) input of a comparator 873, is also charged by the reference voltage (V_{ref}) through a resistor 869. When the voltage on the non-inverting (+) input of the comparator 864 exceeds the voltage on the inverting (-) input of the comparator 864, the comparator 864 outputs a high
10 voltage which causes slow charging voltage of capacitor 872, and that appears on the inverting (-) input of comparator 873. When the voltage on the inverting (-) input of the comparator 873 exceeds the voltage on the non-inverting (+) input of comparator 873, the output of the comparator 873 goes low and
15 will then energize the coil of the relay 852, thereby connecting the speaker 830 to the amplifier 850.

When the power to the system 100 is turned off, the circuit 856 operates as follows. The capacitor 860 rapidly discharges dropping the voltage on the non-inverting (+) input
20 of the comparator 864 beneath the voltage on the inverting (-) input of comparator 864 and thereby turning this comparator off. Consequently, a voltage on the inverting (-) input of the comparator 873 will decrease. This results in the comparator 873 turning off as the voltage on the non-inverting
25 (+) input of comparator 873 is greater than the voltage on the inverting (-) input. With the comparator 873 turned off (output goes high), the coil of the relay 852 is de-energized, which results in the relay 852 disconnecting the speaker 830 from the amplifier 850.

30 Preferably, when the system 100 is powering up, the circuit 856 will delay energizing the coil of the relay 852 to connect the speaker 830 to the amplifier 850 for a relatively long time, preferably approximately four seconds, thereby permitting any transients which would cause damage to the
35 speaker 830 to dissipate. However, after the system 100 is powered down, it will be desirable to quickly disconnect the coil of the relay 852 from the amplifier 850, preferably

within approximately 16 milliseconds, to prevent any transients being transmitted to the speaker 830. The values of component parts of one presently preferred embodiment of circuit 856 are shown in Table 1 below. When used in the circuit configuration shown in Figure 26, a suitably long delay turn-on time with a suitably quick turn-off time is achieved.

TABLE 1

IDENTIFIER	PART	PART NUMBER	VALUE
864	Comparator	LM311	-
873	Comparator	LM311	-
857	Diode	IN4001	-
874	Diode	IN4001	-
858	Resistor	-	10k Ω
859	Resistor	-	4.7k Ω
861	Resistor	-	470 Ω
862	Resistor	-	10k Ω
866	Resistor	-	82k Ω
867	Resistor	-	270 Ω
869	Resistor	-	4.7k Ω
871	Resistor	-	10k Ω
860	Capacitor	-	2.2 μ F/50V
863	Capacitor	-	0.1 μ F
870	Capacitor	-	0.1 μ F
872	Capacitor	-	0.1 μ F
865	Capacitor	-	47 μ F
868	Capacitor	-	0.1 μ F

Figure 27 is a side elevational diagram showing a cross section of another preferred embodiment of a seat and low frequency speaker assembly 880. The purpose of the assembly 880 is also to provide the user 102 (Figure 1) with meaningful and realistic road feel cues. The assembly 880 includes a housing such as a seat 882 that has at least a portion of its interior hollow and includes a recess 884. The recess 884 has the low frequency speaker 881 which is connected to the simulation system 100 in the same manner as is the speaker 830 (Figure 1) mounted and secured such that a diaphragm of the speaker 881 is in communication with the air that is enclosed in the envelope or bladder 886 of the seat. The diaphragm of

speaker 881 moves back and forth in a conventional manner in response to a signal presented at the speaker terminals. This back and forth motion is communicated through the air creating vibration on the surfaces 888 of the seat 882. The surfaces
5 888 are made of a somewhat flexible but strong plastic material. The back and bottom surfaces are somewhat thicker and hence stiffer, while the surfaces in contact with the user 102 (Figure 1) are thinner to flex in response to the vibration of the air. The surfaces in contact with the user
10 102 may be overlaid with a cover and cushion 889.

The speaker 881 of this presently preferred embodiment is a model 40-1348 dual-coil eight inch speaker sold by Radio Shack. The speaker 881 has four terminals, a first set of terminals 890 is visible in Figure 27. The speaker 881 is
15 fastened to the seat 882 by four bolts, the locations of two are indicated by a pair of holes 883a and 883b. The speaker 881 is connected to the control process 120 (Figure 1) of the system 100 through the relay 852, the amplifier 850, and the low pass filter 854 in the same fashion as is the speaker 830
20 in the preferred embodiment shown in Figures 24 and 25. The speaker 881 receives signals indicative of road feel cues in the same fashion as described above.

Figure 28 shows a cross-sectional view of the ABS 900 with the attached brake pedal 106 of the preferred embodiment of the present invention shown in Figure 1. The ABS 900 is
25 mechanically arranged so that the brake pedal 106 provides for movement which simulates the movement of a brake pedal in a real automobile.

The ABS 900 includes a mounting plate 902 having a back side 903 and a front side 905. The mounting plate includes a plurality of mounting holes 904 (one shown) through which screws (not shown) are used to secure the brake system 900 to
30 the housing (not shown) of the simulator system 100 in a similar orientation as brake pedals in a typical automobile.

A connector rod 906 extends through a hole in the
35 mounting plate 902. The portion of the connector rod 906 extending out from the back side 903 of the mounting plate 902

is preferably threaded. Coupled to the threaded portion of the connector rod 906 is a washer 908 which is positioned on the connector rod 906 so as to be sitting adjacent to the back side 903 of the mounting plate 902. A cylindrical elastic bumper 910 having an opening slightly larger than the diameter of the connector rod 906, and a spring 912 are both positioned on the threaded portion of the connector rod 906 adjacent to the washer 908. The inner diameter of the spring 912 is slightly larger than the outer diameter of the bumper 910 so that when the bumper 910 is positioned on the connector rod 906, the spring 912 is then mounted over the bumper 910. A washer 914, capable of retaining and compressing the spring 912, is also positioned on the connector rod 906 so that the spring 912 and the elastic bumper 910 are positioned in axial alignment with the connector rod 906 between the washer 914 and the washer 908. The spring 912 is longer than the elastic bumper 910 so that the spring 912 will have to be compressed before the elastic bumper 910 can make contact with both of the washers 908 and 914 at the same time. A nut 916 adjustably secures the washer 914 to a specified position on the connector rod 906.

The portion of the connector rod 906 which projects out from the front 905 of the mounting plate 902 is connected to a cross piece 918 which, in turn, connects two identical force multiplier arms 919 (one shown). An elastic rebound bumper 920 is positioned on the portion of the connecting rod 906 between the mounting plate 902 and the cross piece 918. The top end of each of the force multiplier arms 919 is respectively bolted to one of two arms 921 of an electrically controlled solenoid 922 in such a manner that when current is supplied to the solenoid 922, the force multiplier arms 919 move in response thereto.

An adjustment screw 928 is also mounted on another cross-piece (not shown) connected between the force multiplier arms 919. The adjustment screw 928 extends through the cross piece connecting the force multiplier arms 919 to a lever arm 926. The adjustment screw 928 permits the user 102 to adjust the

amount of motion of the force multiplier arms 919, relative to the lever arm 926, induced by the solenoid 922. Hence, tightening the adjustment screw 928 decreases the amount by which the force multiplier arms 919 can travel relative to the lever arm 926. The bottom ends of both of the force multiplier arms 919 are connected via a bolt 932 and a nut (not shown) to a brake pedal member 930. The solenoid 922 is secured to the top of a plate 924. The bottom surface of the plate 924 is, in turn, secured to the lever arm 926 which projects perpendicularly downward from the plate 924.

The lever arm 926 is welded near its bottom end to the brake pedal member 930 along the length of the lever arm 926 intersecting the surface of the brake pedal member 930. A strain gauge 934 is preferably bonded to the material of the lever arm 926 in a position to sense strain in the lever arm 926 as force is applied to the brake pedal 106. The strain gauge 934 is of conventional structure and may be either of the metallic or semiconductor type. The strain gauge 934 is essentially a serpentine resistive path that will either elongate or shorten as strain is applied to the lever arm 926 thereby resulting in a change of resistance, which can be detected by an appropriate electrical circuit to be discussed below.

The brake pedal member 930 is a substantially L-shaped member which initially extends substantially downward from the force multiplier arms 919 and then extends substantially outward from the mounting plate 902 to where the brake pedal member 930 terminates in the brake pedal 106. The brake pedal 106 preferably is identical to typical brake pedals in real automobiles. The brake pedal member 930 is also fixedly connected to a pivot bearing member 938. The pivot bearing member 938 preferably comprises a metal cylinder which is horizontally mounted between two rectangular securing members 940 (one shown) which are mounted on the front side 905 of the mounting plate 902.

The mechanical operation of the brake system 900 will now be described in conjunction with Figures 1 and 28. In

response to conditions observed from the simulator 100, the user 102 places his foot upon the brake pedal 106 and depresses it in the same fashion as a driver would depress a brake pedal in an actual car. In response to the force
5 resulting from the user 102 depressing the brake pedal 106, the brake pedal member 930 pivots about the pivot bearing member 938 in the direction of an arrow 942. This causes the segment of the brake pedal member 930 above the pivot bearing 938 to be urged to move in the direction depicted by an arrow
10 944. Since the segment of the brake pedal member 930 above the pivot bearing 938 is coupled to the force multiplier arms 919, the force multiplier arms 919 will also be urged to move in the direction of the arrow 944. Movement of the force multiplier arms 919 in the direction of the arrow 944 causes
15 the connector rod 906 attached thereto to also move in the same direction, which is the positive X-direction in Figure 28.

Since the connector rod 906 includes an attached washer 914 and nut 916, movement of the connector rod 906 in the
20 direction of the arrow 944 also results in movement of the washer 914 and nut 916 in the positive X-direction. As the washer 914 is moved in the positive X-direction, it compresses the spring 912, which in turn causes linearly increasing force to be exerted against the washer 914 in the negative X-
25 direction. Eventually, the spring 912 will be compressed to the point where the washer 914 will make contact with the elastic bumper 910. At that point, greater force will be exerted against the washer 914 in the negative X-direction. When the user 102 stops depressing the brake pedal 106 in the
30 direction of arrow 942, the spring 912 will push the washer 914 and the connector rod 906 in the negative X-direction to their initial position, which will in turn cause the force multiplier arms 919, the brake pedal member 930 and the brake pedal 106 to return to their initial undepressed position. As
35 can be appreciated, the amount of force exerted by the spring 912 and the elastic bumper 910 in opposition to the user 102 depressing the brake pedal 106 in the direction of the arrow

942 can be adjusted by positioning the washer 914 at a different location along the connector rod 906 and securing it thereto with the nut 916.

Depression of the brake pedal 106 in the direction of arrow 942 in this manner also results in straining the lever arm 926 causing the serpentine resistive path of the strain gauge 934 to either shorten or lengthen thereby changing its measured resistance. The strain gauge 934 is electrically connected to the control process 120 of the computer 114 as shown in Figure 1. As can be appreciated, additional electronic circuitry is required to translate the change in resistive value of the strain gauge 934 due to increased strain upon the lever arm 926 into an electronic signal that the computer 114 can utilize. Consequently, this embodiment of the invention includes a bridge/interface circuit 946 (see Figure 1) of a type available in the marketplace. Generally, the resistance of the strain gauge 934 changes very little during strain of the material of the lever arm 926, hence, the bridge/interface circuit 946 includes bridge circuitry which may be used to detect the slight changes in the resistance of the strain gauge 934. Further, the bridge/interface circuit 946 also includes interface circuitry which will convert the analog bridge circuit output signal to a digital format suitable for use by the control process 120. As can be appreciated by one skilled in the relevant technology, one of the difficulties of using strain gauges, and particularly sensitive silicon based strain gauges, is that these gauges have temperature drift characteristics which result in inaccurate readings. It is desirable that the bridge is balanced in the quiescent state when no strain is being experienced by the lever arm 926 to minimize these effects.

Specifically, the presently preferred bridge/interface circuit is substantially the same as the circuit shown in Figure 28 of U.S. Patent No. 4,949,119 to Moncrief, et al. The desirability of using such a circuit was described in this patent at Column 7, lines 3-60, and the manner in which this circuit operated, both as a balancing bridge and as a analog

to digital converter is described in detail at Column 9, line 16 to Column 10, line 32. U.S. Patent No. 4,949,119 to Moncrief, et al., is hereby incorporated by reference.

5 The ABS 900, shown in Figure 28, simulates the feeling
the user 102 will feel through his foot when he is depressing
the brake pedal 106 with sufficient force such that an ABS
would typically be activated in a real world automobile. As
previously described, in this preferred embodiment, when the
10 user 102 depresses the brake pedal 106, a strain will be
induced upon the lever arm 926 which will then be detected by
the strain gauge 934. The strain gauge 934 is coupled to the
bridge/interface circuit 946 which detects and translates the
signal detected by the strain gauge into a signal which can be
processed by the computer 114, and specifically the control
15 process 120.

If this signal indicates that the user 102 is depressing
the brake pedal 106 with substantially the same amount of
force that would activate a typical ABS in real-world
automobiles, the control process 120 sends a pulsating voltage
20 signal to the solenoid 922. In response to this pulsating
voltage, the solenoid 922 will cause the solenoid arms 921 to
move back and forth in the positive and negative X-direction.
This movement of the solenoid arms 921 causes the force
multiplier arms 919 to vibrate. Since the force multiplier
25 arms 919 are connected to the brake pedal member 930 which is
in turn connected to the brake pedal 106, vibration of the
force multiplier arms 919 will ultimately be felt by the user
102 as he depresses the brake pedal 106. As can be
appreciated by a person skilled in the technology, the
30 amplitude of this induced vibration of the force multiplier
arms 919 can be controlled by tightening or loosening the
adjustment screw 928 attached thereto. Consequently, by
adjusting the screw 928, the vibration felt by the user 102
while depressing the brake pedal 106 can be made to
35 approximate the feeling of an actual brake pedal in an actual
ABS equipped car when the ABS brakes are being applied.

In this presently preferred embodiment, the control

process 120 will continue to send the pulsating voltage to the solenoid 922 so long as the simulated vehicle is still moving and the user 102 is still depressing the brake pedal 106 with sufficient force to initiate the pulsating voltage. The
5 pulsating voltage preferably has a 40 msec pulse width with a cycle period of 100 msec.

Although the preferred embodiments of the present invention have been principally shown and described as relating to vehicle simulators such as a driver training
10 system, the present invention could also be used for other types of simulations. The embodiments of the invention hereinabove have several significant advantages over the prior art. Specifically, the simulation system that the Applicant has disclosed is capable of generating and transmitting a wide
15 variety of road feel cues to the user of the simulator. These road feel cues can be stored and recalled when an event occurs within the simulated universe which would normally trigger a specific road feel in a real world automobile, e.g., hitting a bump, etc., and are transmitted to the user by a mechanism
20 which can accommodate and transmit a large number of feelings.

Further, the simulation system that Applicant has disclosed also realistically represents the feel that the vehicle controls would have when operating in the real world. Specifically, the driving embodiment of the present invention
25 includes a steering wheel with feedback as well as a brake pedal which simulates the feeling of ABS brakes. A simulation system with these features provides a more realistic representation of the real world, and as such, provides a better educational experience of how to operate this vehicle
30 in the real world.

Although the above detailed description has shown, described and pointed out fundamental novel features of the invention as applied to the various embodiments discussed above, it will be understood that various omissions and
35 substitutions and changes in the form and details of the device illustrated may be made by those skilled in the art, without departing from the spirit of the invention. The

described embodiments are to be considered in all respects only as illustrative and not restrictive.

WHAT IS CLAIMED IS:

1. A driver training system for a user of a simulated vehicle, comprising:

5 a plurality of simulated input devices for controlling the simulated vehicle;

a video display for presenting the user with a view of a simulated environment;

10 modeling means responsive to the input devices for determining position information of the simulated vehicle in the simulated environment;

means responsive to the position information for displaying on the video display a present route of the simulated vehicle through the simulated environment; and

15 means responsive to at least one of the simulated input devices for displaying on the video display a plurality of states of the input device at selected times in the present route.

2. The system defined in Claim 1, wherein the means for displaying the input device state includes a memory from which
20 is retrieved and simultaneously displayed the input device states from a previous route.

3. The system defined in Claim 2, wherein the means for displaying the input device state includes user selectable means for storing the input device states of the present route
25 into the memory.

4. A driver training system for a user of a simulated vehicle, comprising:

a plurality of simulated input devices for controlling the simulated vehicle;

30 a video display for presenting the user with a view of a simulated environment;

modeling means responsive to the input devices for determining position information of the simulated vehicle in the simulated environment;

35 means responsive to the position information for displaying on the video display a present route of the simulated vehicle through the simulated environment;

means for storing the present route and a plurality of states of at least one input device in a memory; and

means for replaying the present route on the video display and moving the input device according to the states stored in the memory.

5 5. A driver training system for a user of a simulated vehicle, comprising:

 a plurality of simulated input devices for controlling the operation of the simulated vehicle;

10 modeling means responsive to the input devices for determining position information of the simulated vehicle in a simulated environment;

 a video display for presenting the user with a view of the simulated environment;

15 means for providing feedback to the user through a selected one of the simulated input devices; and

 means, responsive to the position information, for providing low frequency sound to the user.

20 6. The driver training system of Claim 5, wherein the selected simulated input device is a brake pedal.

 7. The driver training system of Claim 6, wherein the feedback means provides a sensation representative of an antilock braking system.

25 8. The driver training system of Claim 7, wherein the feedback means comprises:

 a sensor mounted on the brake pedal for sending a signal indicative of the force with which the user depresses the brake pedal to a processor for determining when the feeling of antilock brakes should be simulated;

30 and

 a solenoid for vibrating the brake pedal in response to signals from the processor.

 9. The driver training system of Claim 5, wherein the sound providing means comprises:

35 means for storing signals representative of a low frequency sound;

 means for processing signals retrieved from the

signal storing means; and

means for transducing signals received from the processing means into low frequency sound.

5 10. The driver training system of Claim 9, wherein the signal storing means includes signals representative of the physical sensation of the simulated vehicle colliding with an object.

11. The driver training system of Claim 9, wherein the stored signals comprise digital signals and the processing means comprises:

a digital to analog converter receiving the digital signals from the signal storage means;

a filter receiving analog signals from the converter; and

15 an amplifier receiving a filtered signal from the filter.

12. The driver training system of Claim 11, wherein the filter is a low pass filter.

13. The driver training system of Claim 9, wherein the transducing means comprises:

a speaker providing an audio signal to a chamber; and

a semi-rigid diaphragm connected to the chamber which vibrates in response to the audio signal.

25 14. A method of hazing a plurality of polygons in a computer having a video display, the method comprising the steps of:

selecting one of the polygons;

calculating a haze value as:

30 haze value = $(z * kval) / dimval$

where

z is the distance between the camera position and the polygon,

kval is a constant, and

35 dimval is the distance for full hazing;

calculating a shade value as the dot product of a sun vector and the normal to the polygonal plane;

indexing a dither table with the haze and shade values for dither color offsets;

adding a base color to the dither color offsets for dither colors;

5 determining a dither pattern of dither colors based on the position of the selected polygon; and

drawing the selected polygon on the video display using the dither pattern.

10 15. A turn signal assembly for a steering wheel, comprising;

 a lever;

 a frame;

15 a retainer plate rigidly connecting to one end of the lever and axially coupled to the frame about a pivot point;

 a plunger mounted in a bore in the frame wherein the plunger is biased;

 means in the assembly for selectively engaging detents in the retainer plate; and

20 a cancel pin connected to a hub area, the hub area connected to the steering wheel so that the cancel pin forces the plunger into the bore when the hub area is turned one direction, and pushes against the released plunger when the hub area is turned the other direction thereby forcing detent disengagement and reengagement.

25 16. A low frequency sound generator, comprising:

 a set of input devices;

 a computer for receiving input signals from the input devices;

30 a control process executed by the computer for selectively converting the input signals into output signals indicative of a simulated environment;

 a low pass filter for filtering the output signals;

 an amplifier for amplifying the filtered signals;

35 a speaker for receiving the amplified signals and generating low frequency sounds; and

 a housing having a bladder filled with air wherein

the speaker is secured to the housing so as to be in mechanical communication with the air in the bladder.

17. A low frequency sound system, comprising:

a seat;

5 a plurality of input devices;

a computer for receiving input signals from the input devices;

a control process executed by the computer for selectively converting the input signals into a plurality of output signals; and

10 a transducer for communicating the output signals to the seat.

18. A system for simulating the physical sensations of a brake pedal during operation of an antilock braking system, comprising:

15 means for detecting when the brake pedal is depressed;

means, responsive to the detecting means, for determining the activation of an antilock braking system; and

20 means, responsive to the determining means, for providing feedback indicative of an antilock brake system to the brake pedal.

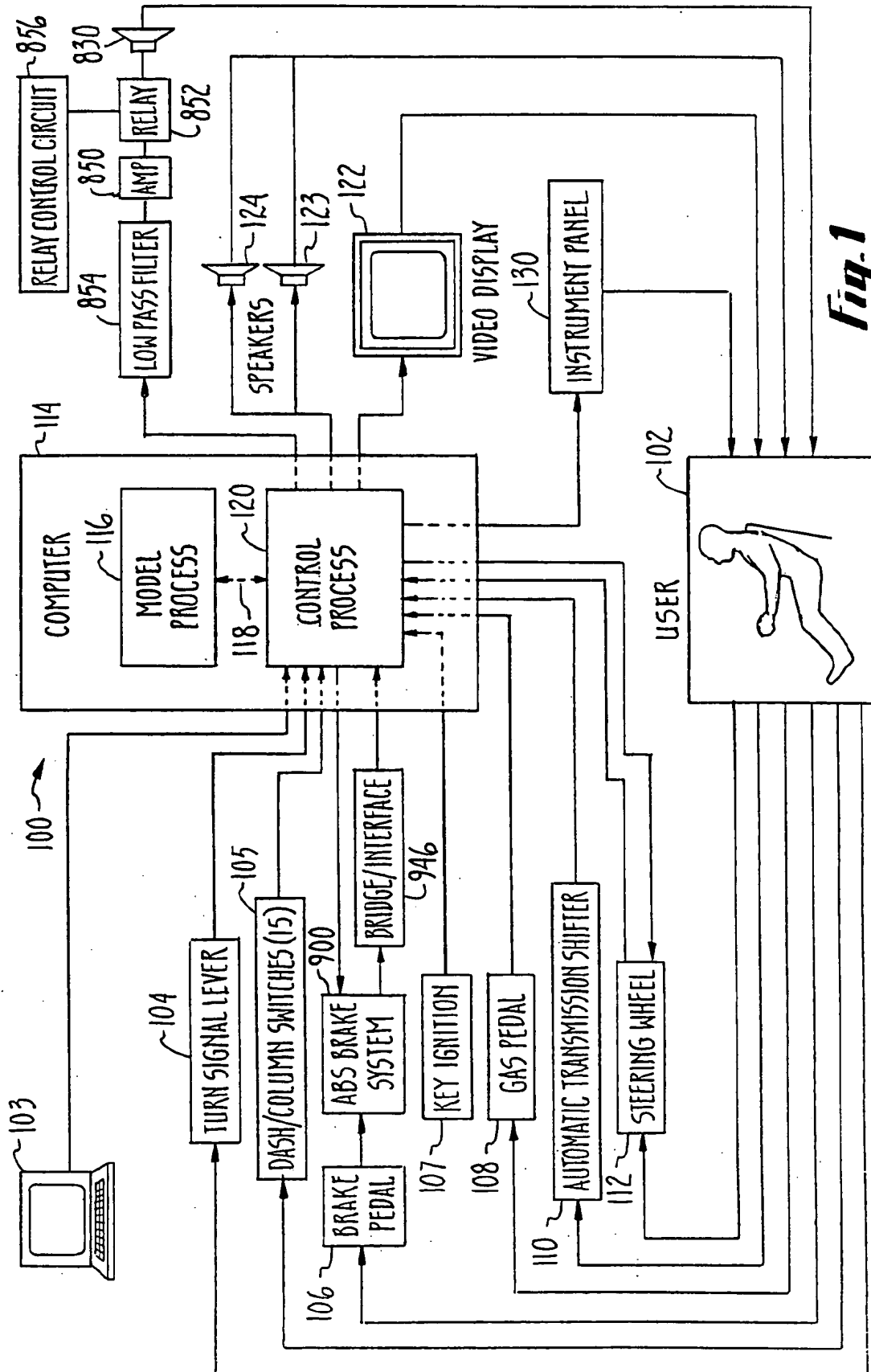


Fig. 1

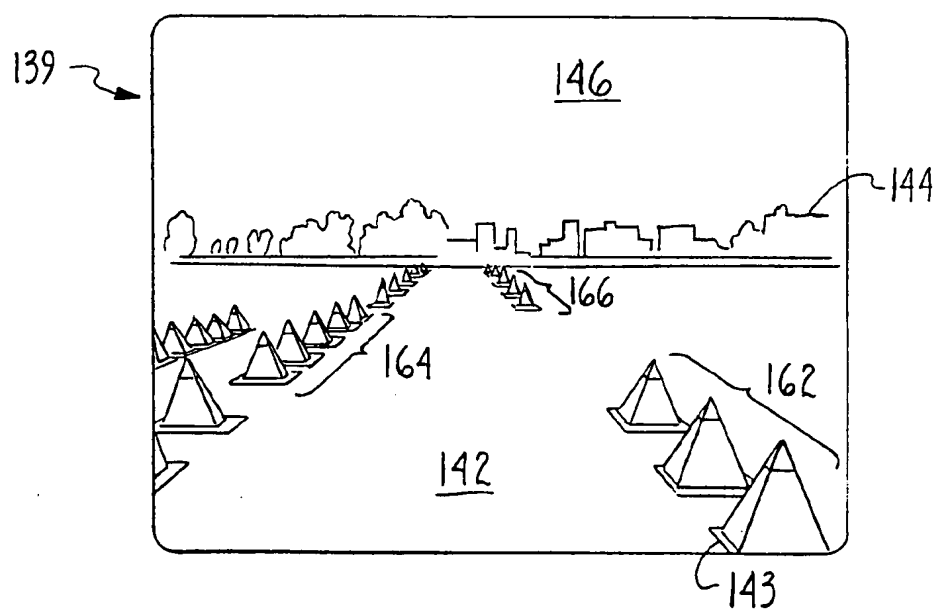


Fig. 2

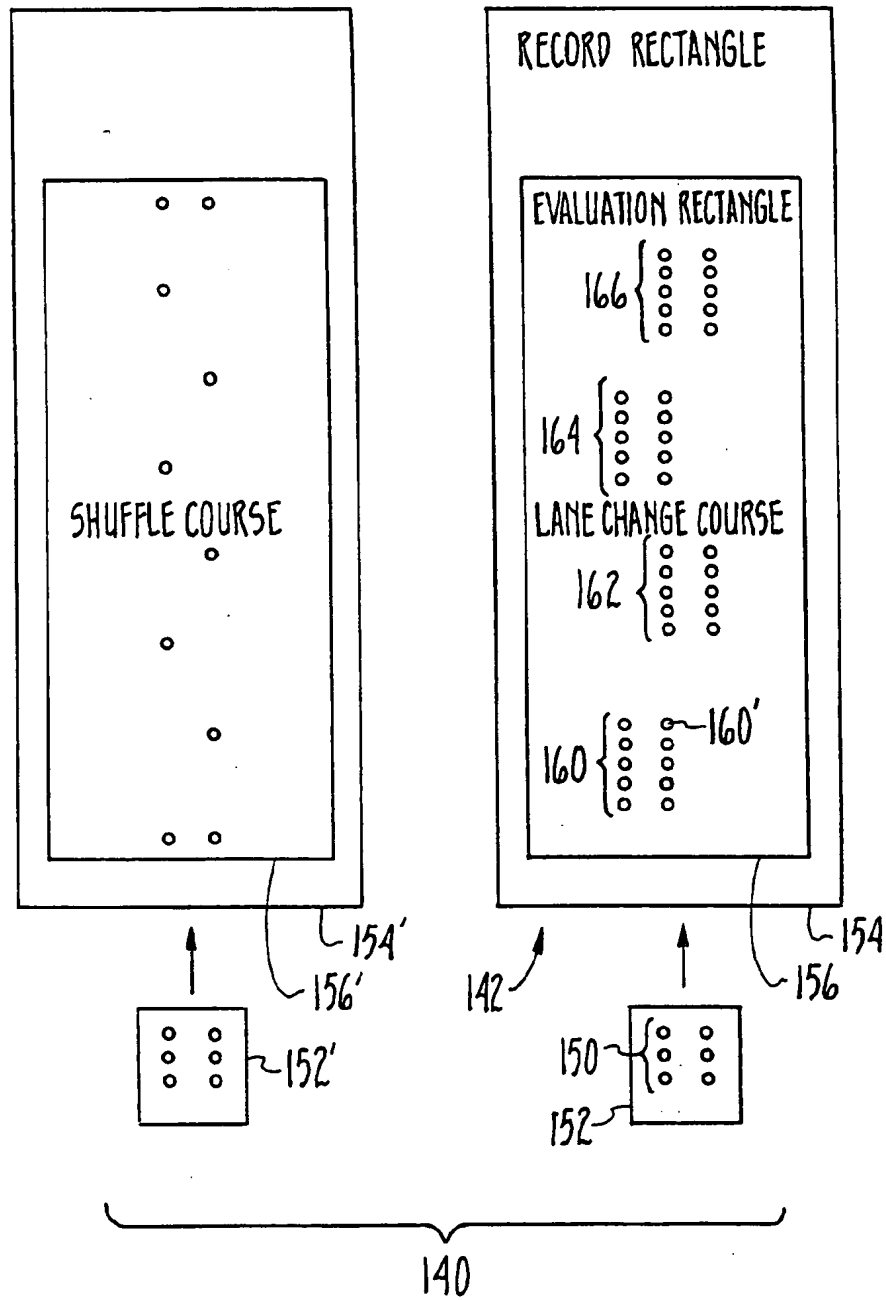


Fig. 3

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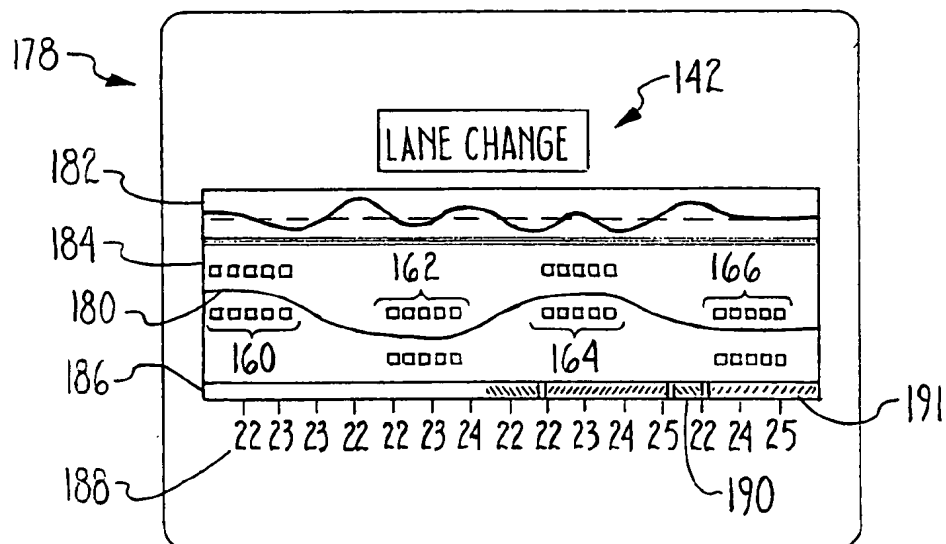


Fig. 4a

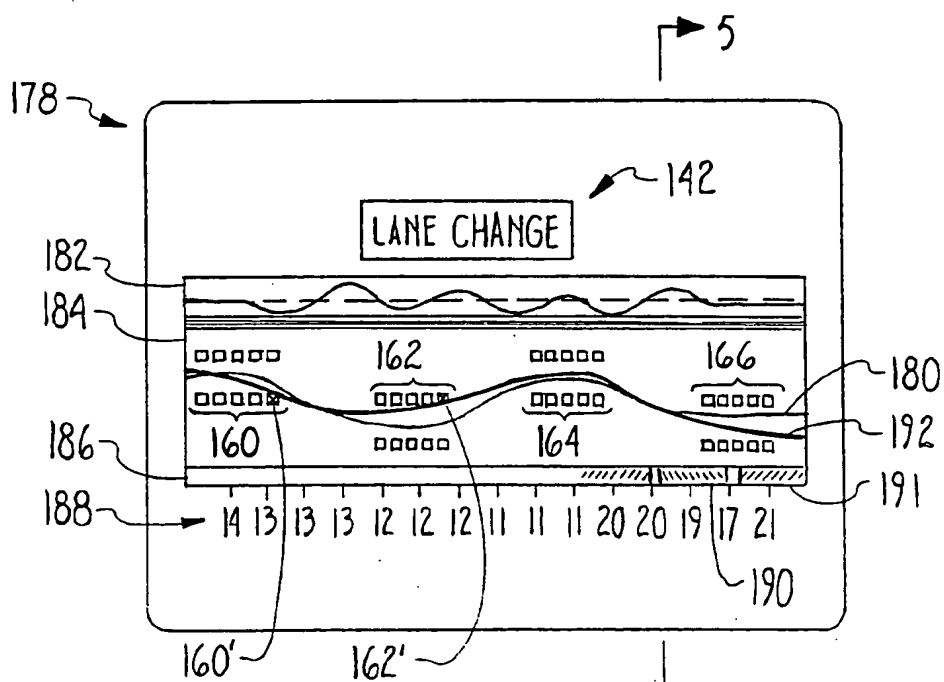


Fig. 4b

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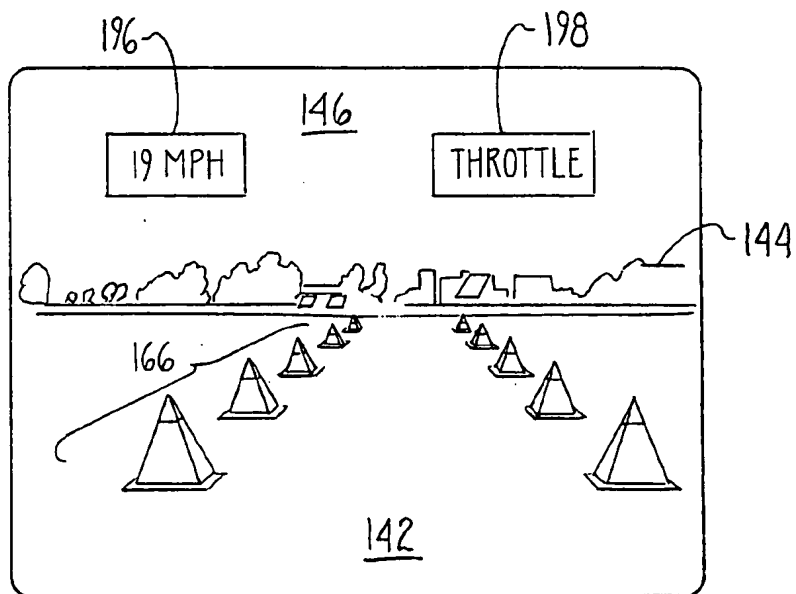


Fig. 5

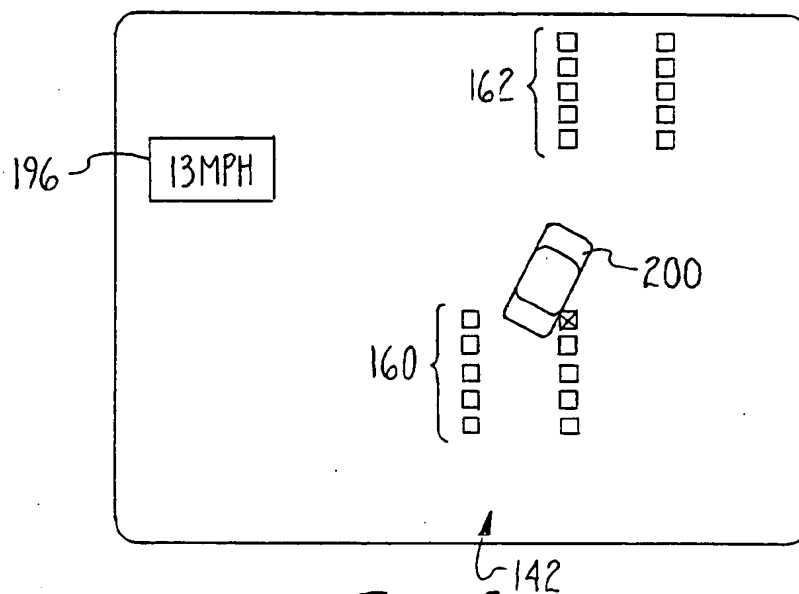


Fig. 6

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220 { 220a TRACK: JUDGEMENT
 220b VEHICLE: POLICE
 220c WEATHER: DAY

222a	MAIN MENU	} 222
222b	START SCENARIO	
222c	SELECT TRACK	
222d	SELECT VEHICLE	
222e	SELECT WEATHER	

Fig. 7

TRACK: JUDGEMENT
 VEHICLE: POLICE
 WEATHER: DAY

	TRACK MENU	} 230
230a	JUDGEMENT TRACK	
230b	STEERING TRACK	
	AUTOCROSS TRACK	
	SPEED TRACK	
	PURSUIT TRACK (SOLO)	
	PURSUIT TRACK (BACKUP)	
	PURSUIT TRACK (CHAOS)	
230c	MAIN MENU	}
	START SCENARIO	

Fig. 8

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TRACK: JUDGEMENT
VEHICLE: POLICE
WEATHER: DAY

VEHICLE MENU	
POLICE CRUISER	} 236
SPORT SEDAN	
COUPE	
ROADSTER	
MAIN MENU	
START SCENARIO	

Fig. 9

TRACK: JUDGEMENT
VEHICLE: POLICE
WEATHER: DAY

WEATHER MENU	
DAY	} 240
NIGHT	
DAWN	
DUSK	
FOG	
SNOW	
MAIN MENU	
START SCENARIO	

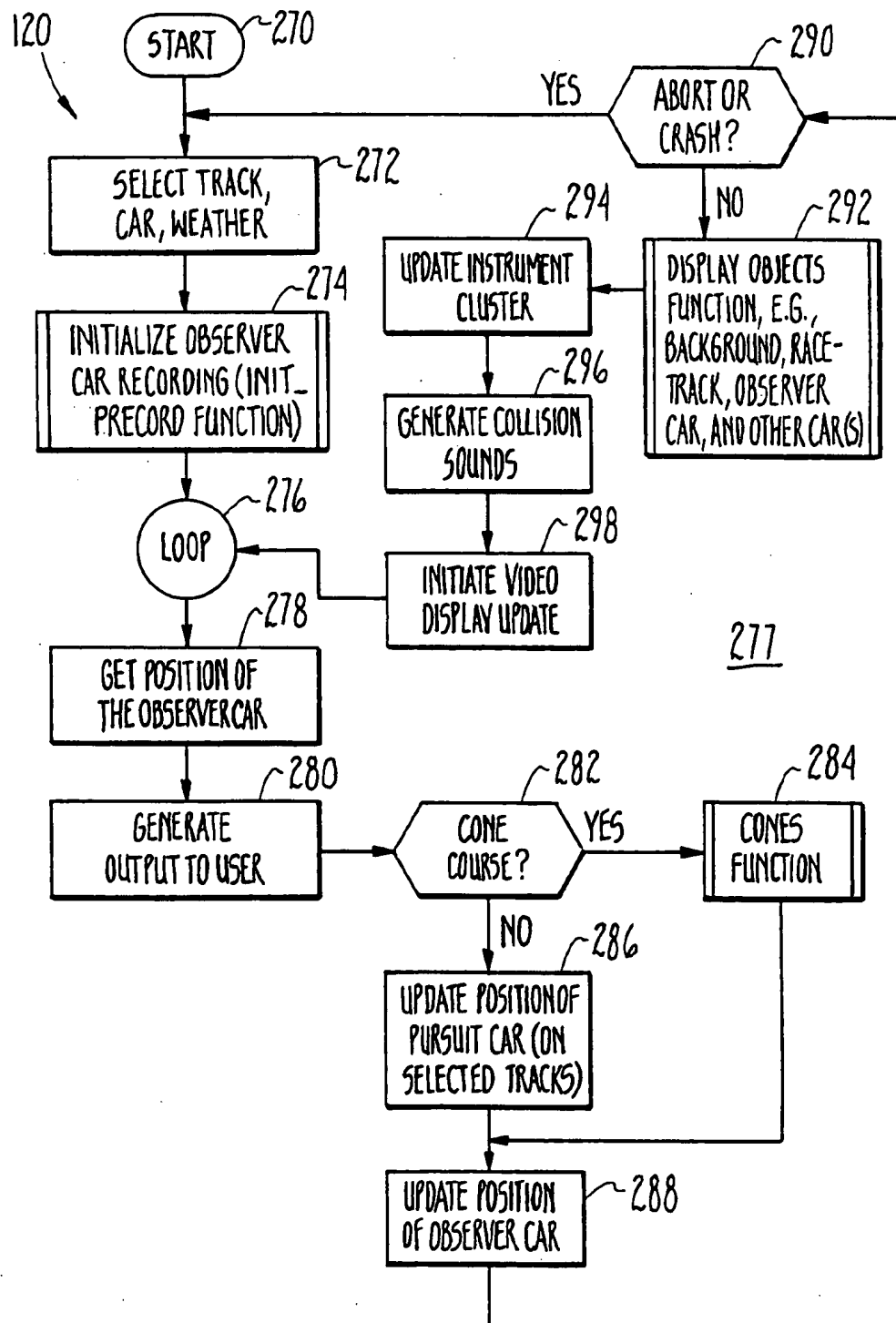
Fig. 10

INSTRUCTION OPTIONS MENU	
SUMMARY EVALUATION	} 244
REPLAY IDEAL PATH - EYE VIEW	
REPLAY STUDENT'S PATH - EYE VIEW	
REPLAY STUDENT'S PATH - TOP VIEW	
SAVE IDEAL PATH	
REPLAY SPEED	
AUTO EVAL ENABLED/DISABLED	
EXIT	

Fig. 11

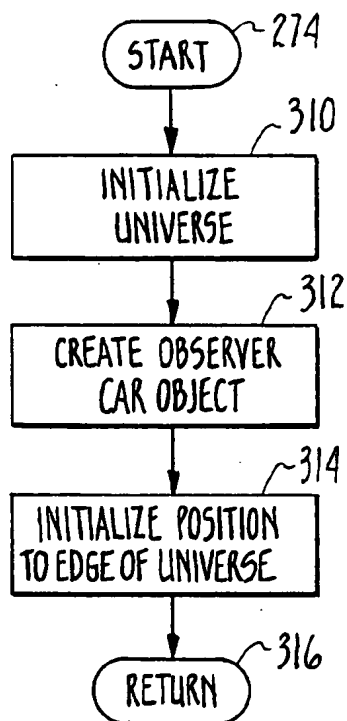
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EXECUTIVE_CONTROL

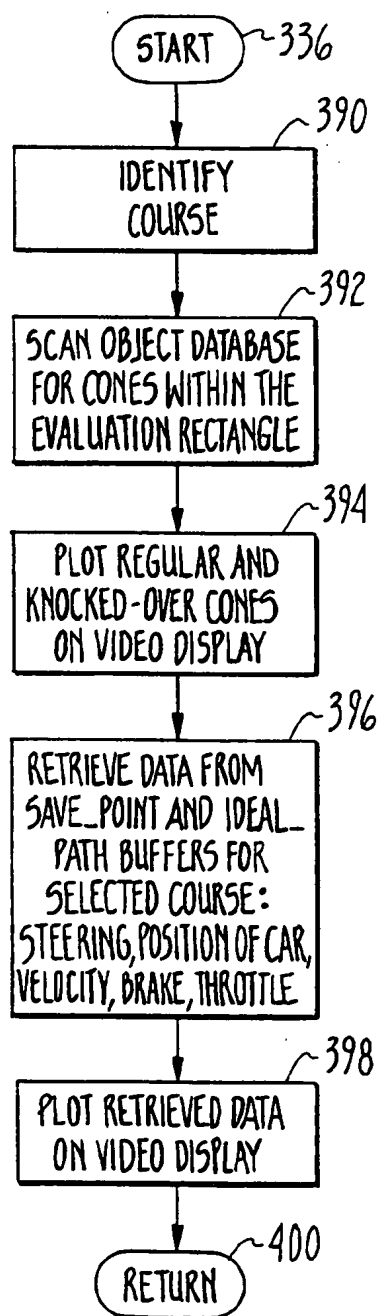
*Fig. 12*

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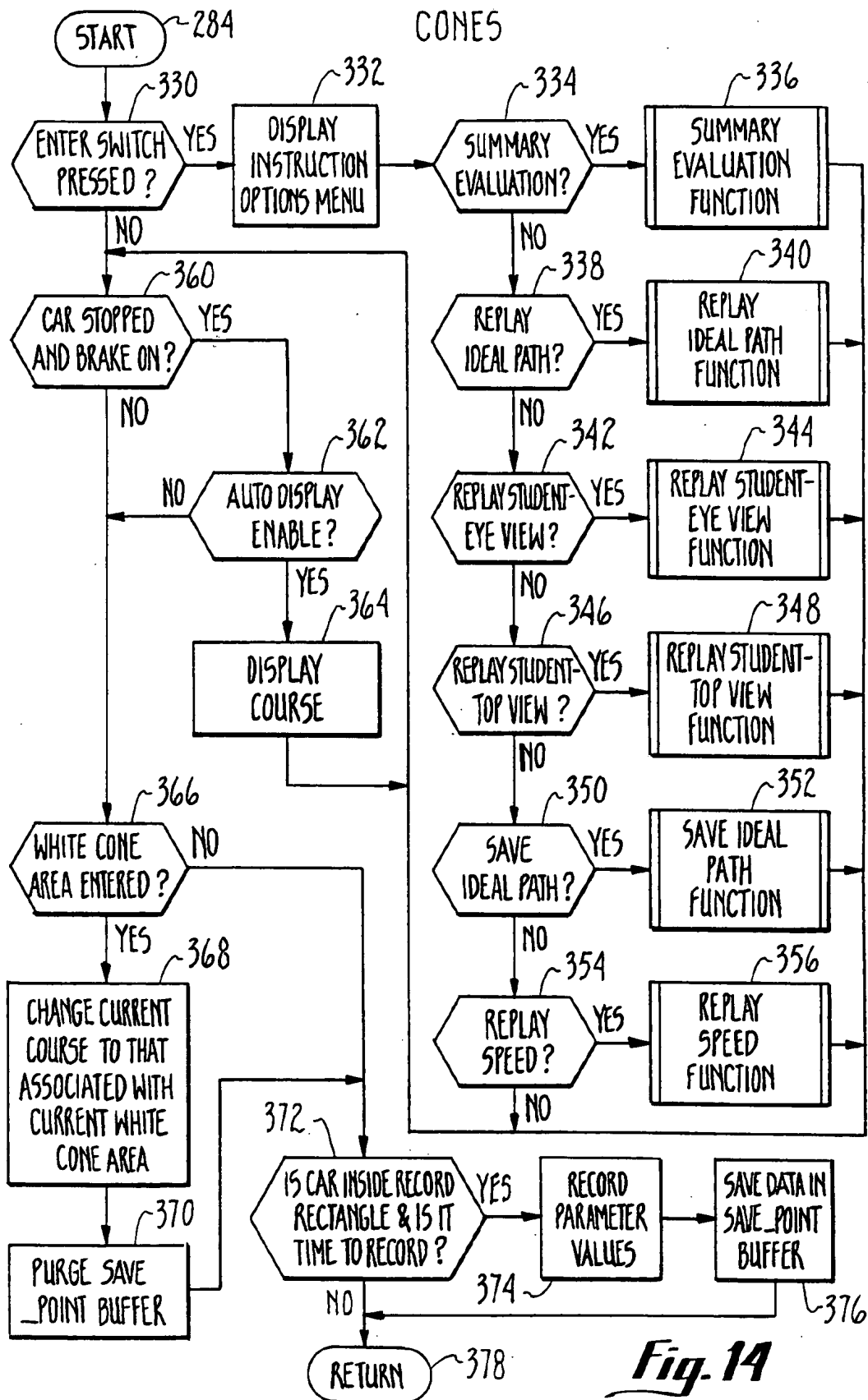
INIT_PRECORD

*Fig. 13*

SUMMARY_EVALUATION

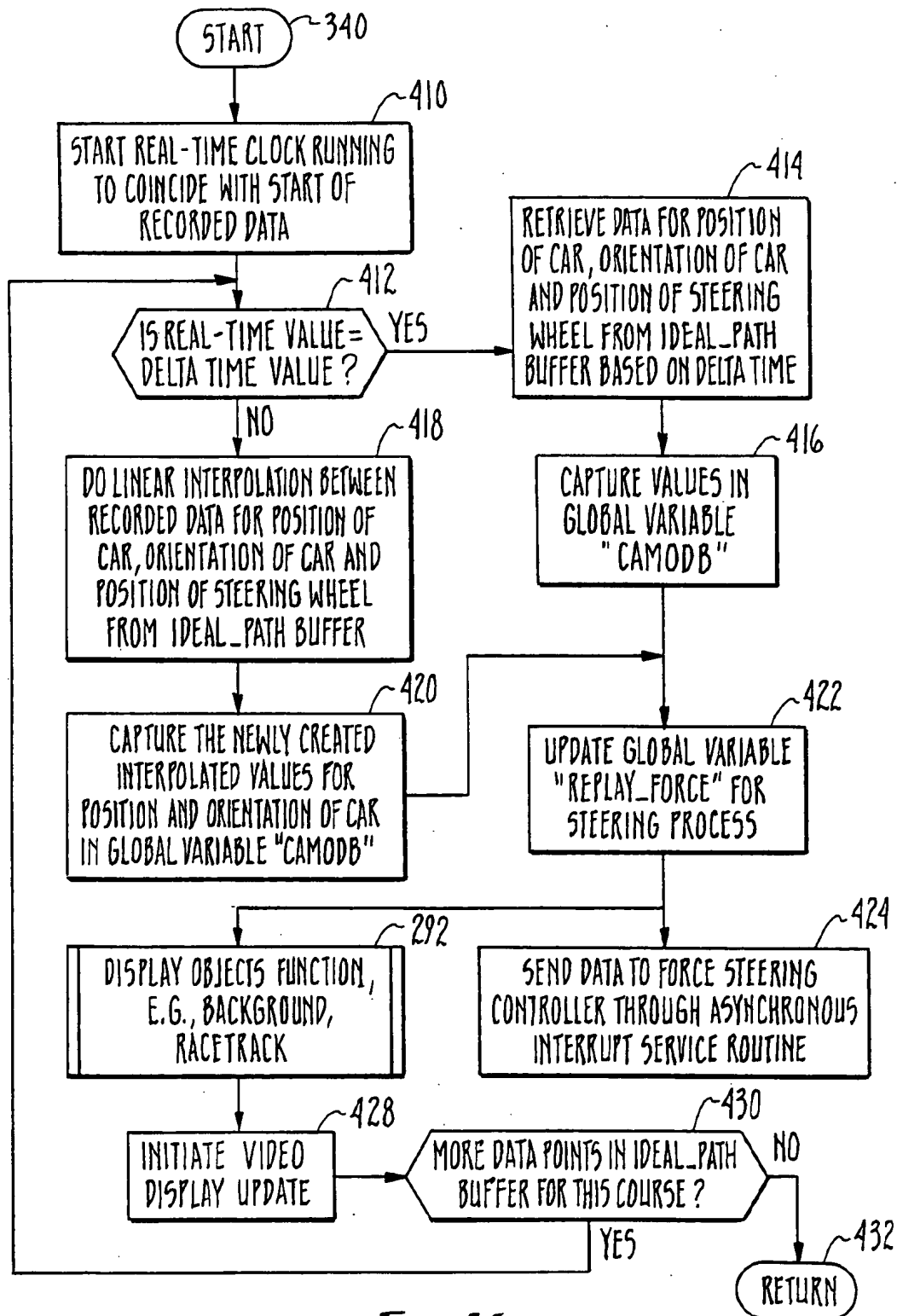
*Fig. 15*

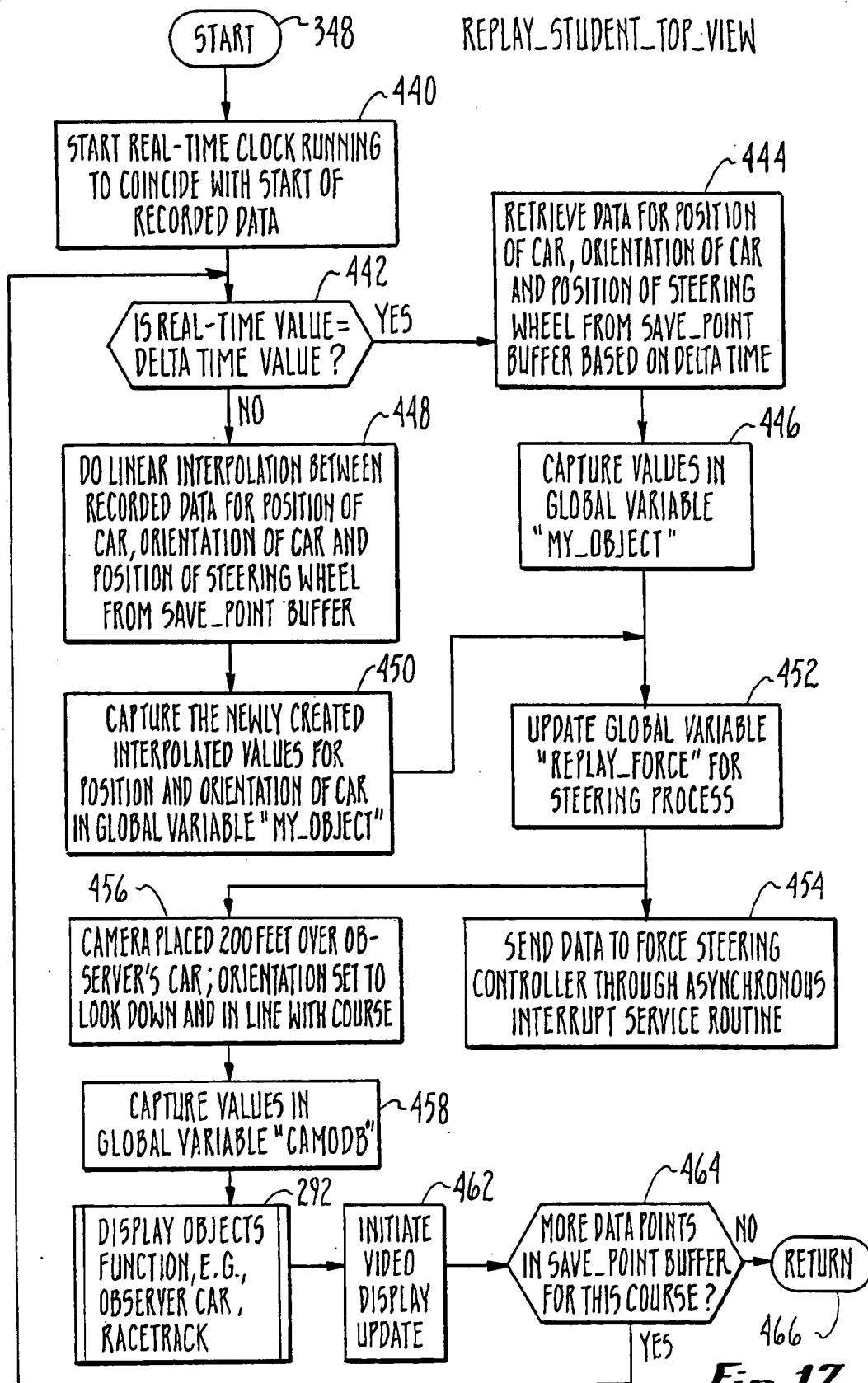
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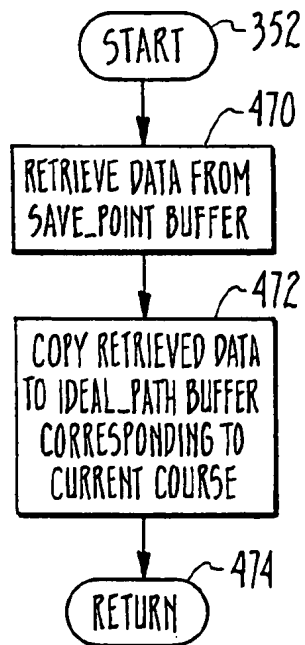
REPLAY_IDEAL_PATH

*Fig. 16*

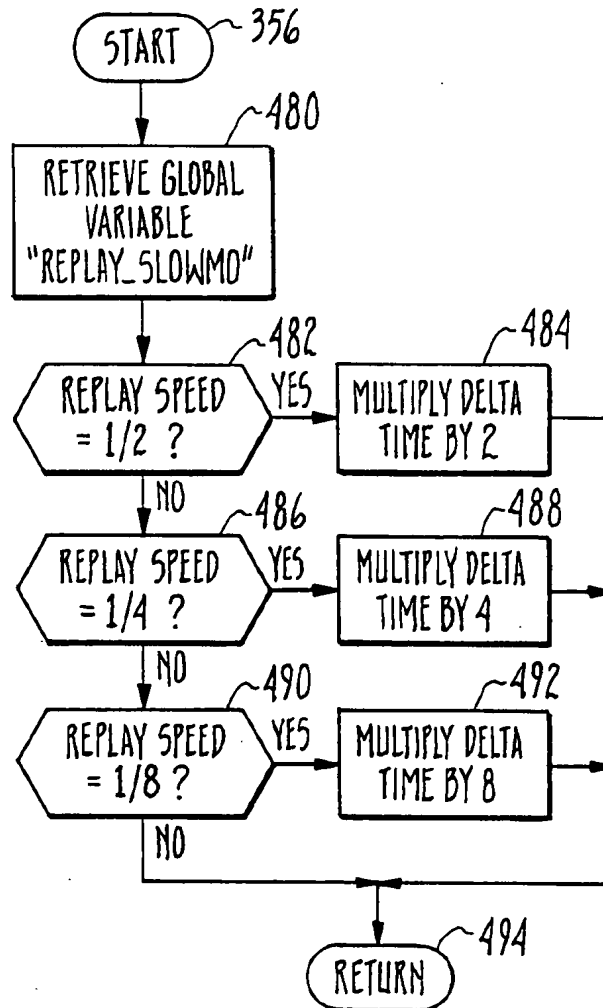


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SAVE_IDEAL_PATH

*Fig. 18*

REPLAY_SPEED

*Fig. 19*

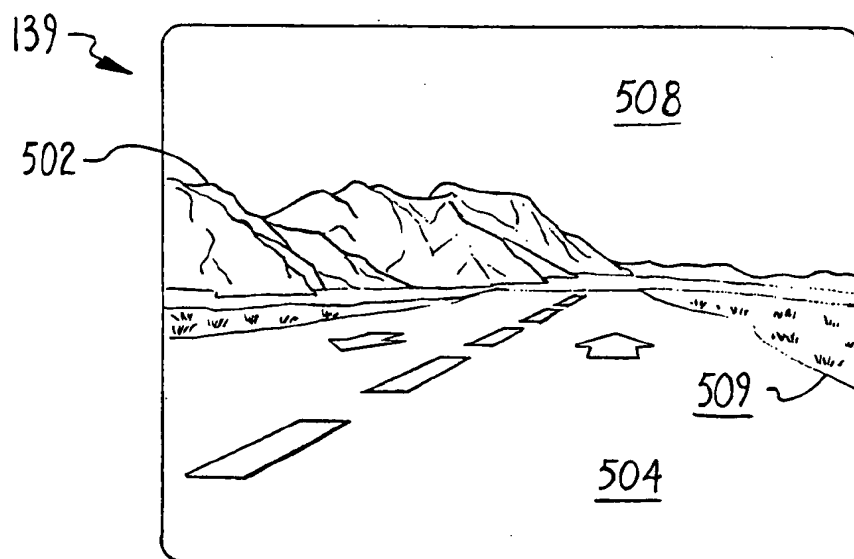


Fig. 20a

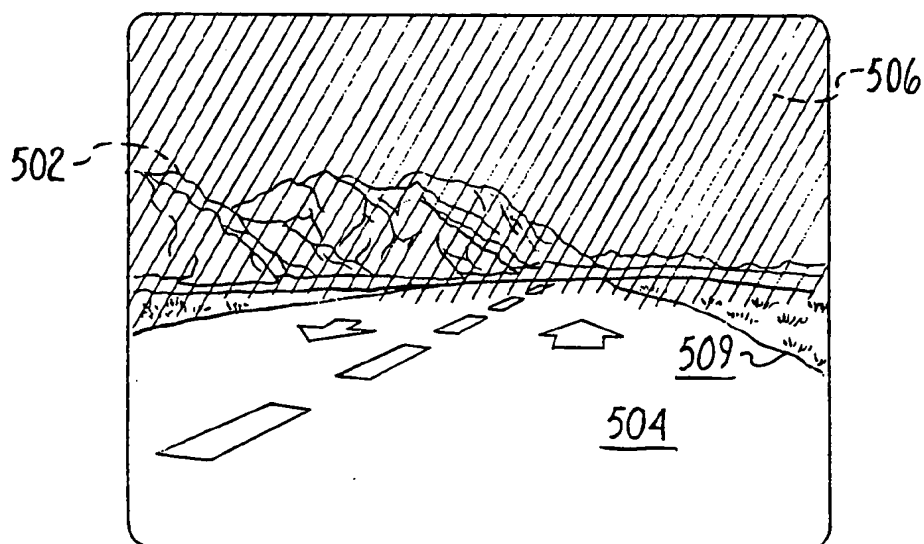
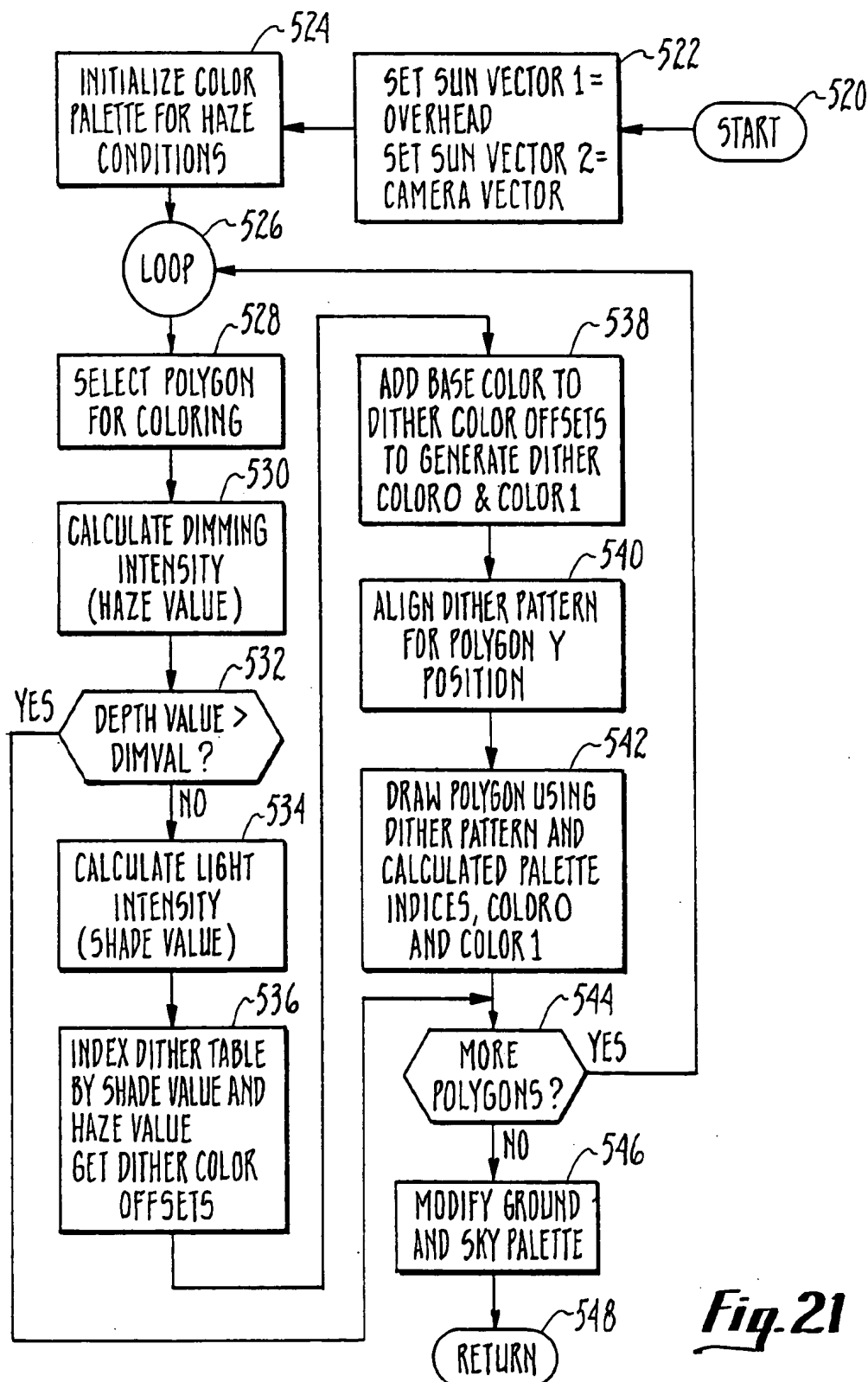
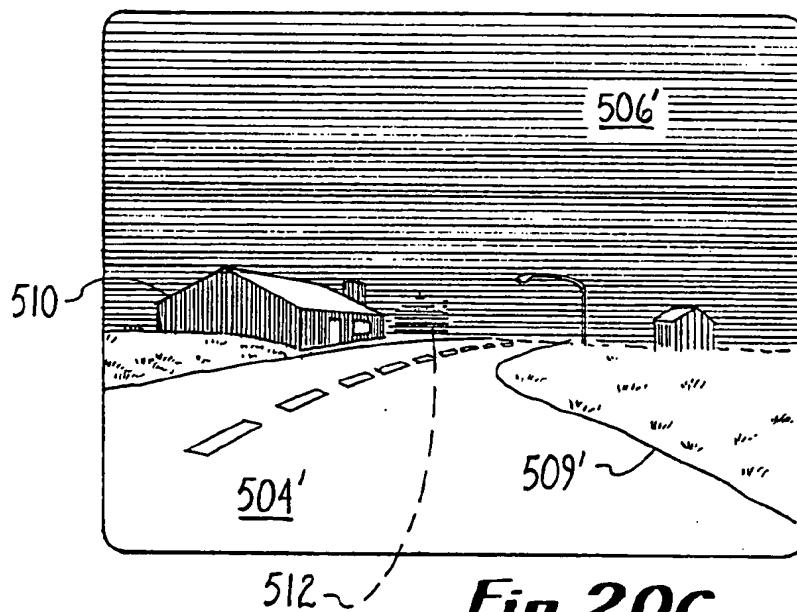
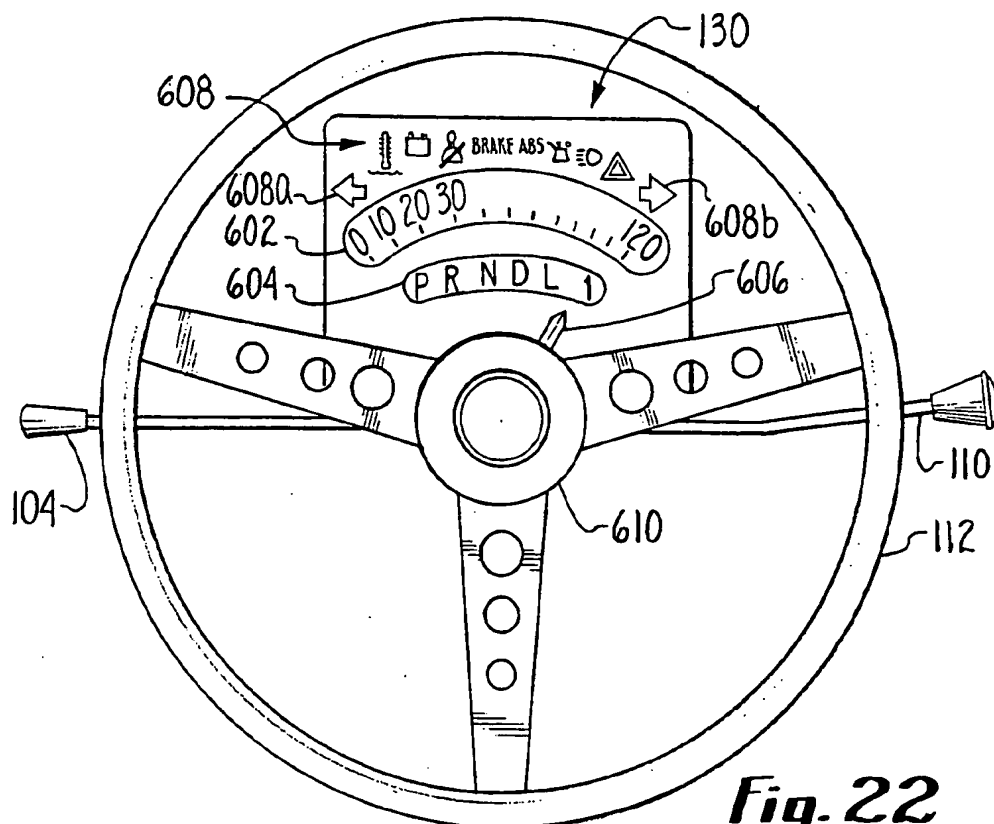


Fig. 20b

ATMOSPHERIC_EFFECTS

*Fig. 21*

*Fig. 20c**Fig. 22*

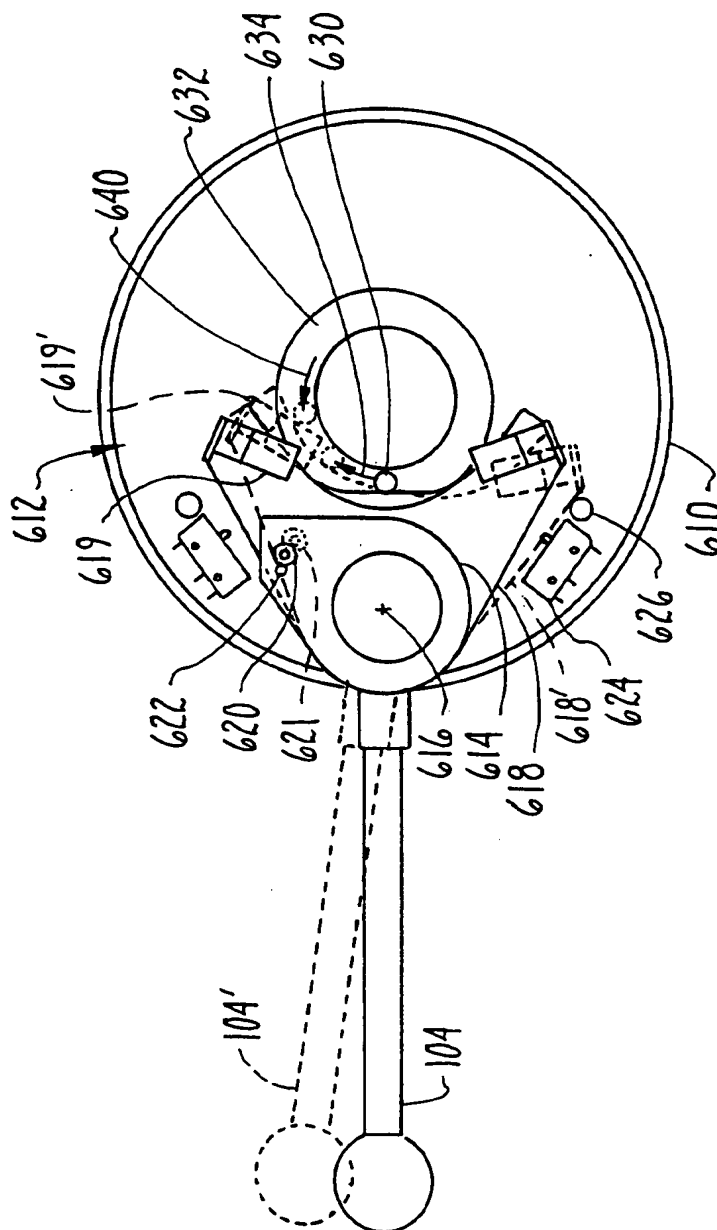
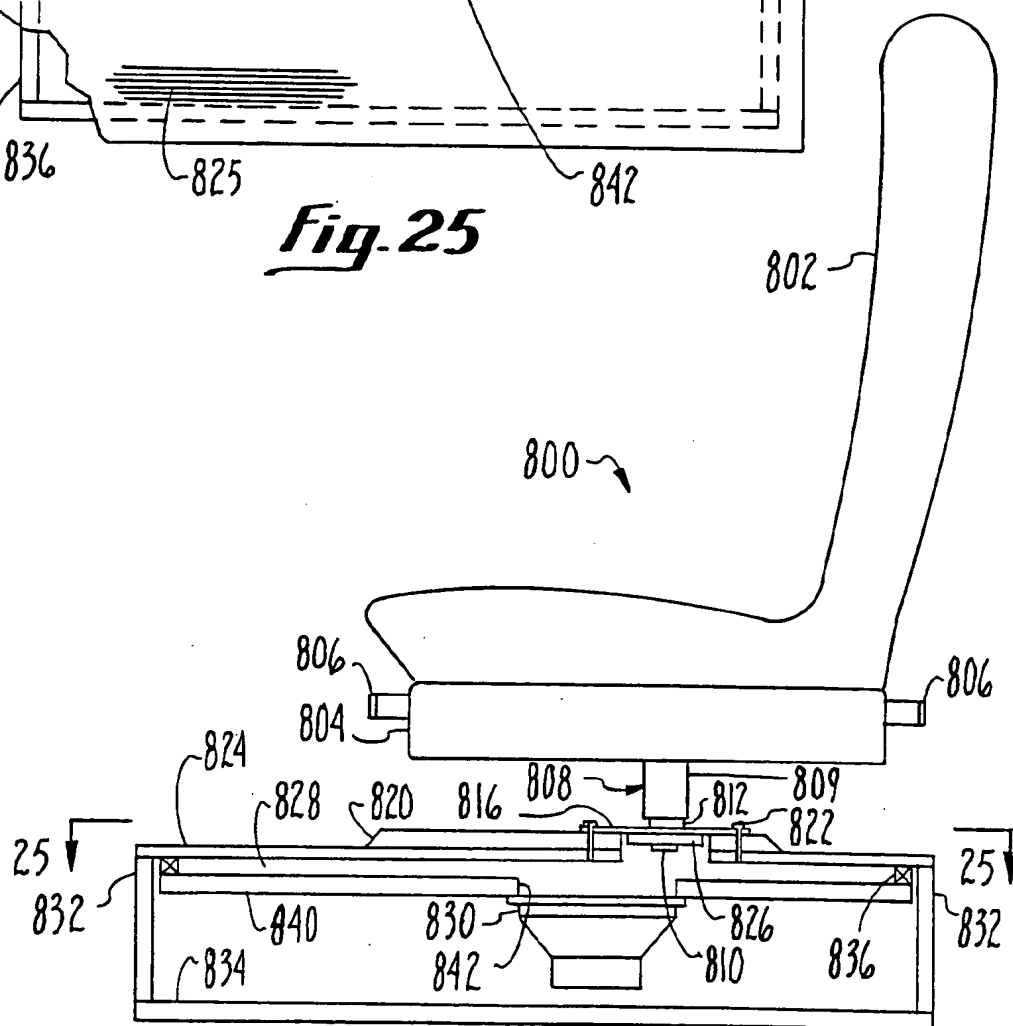
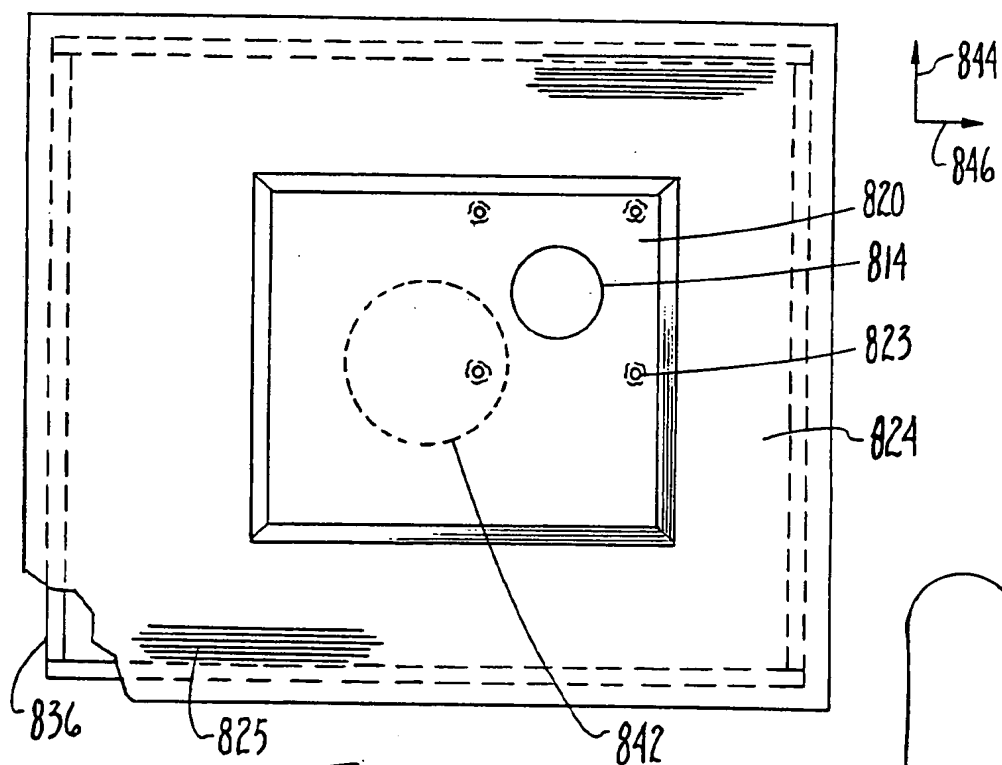
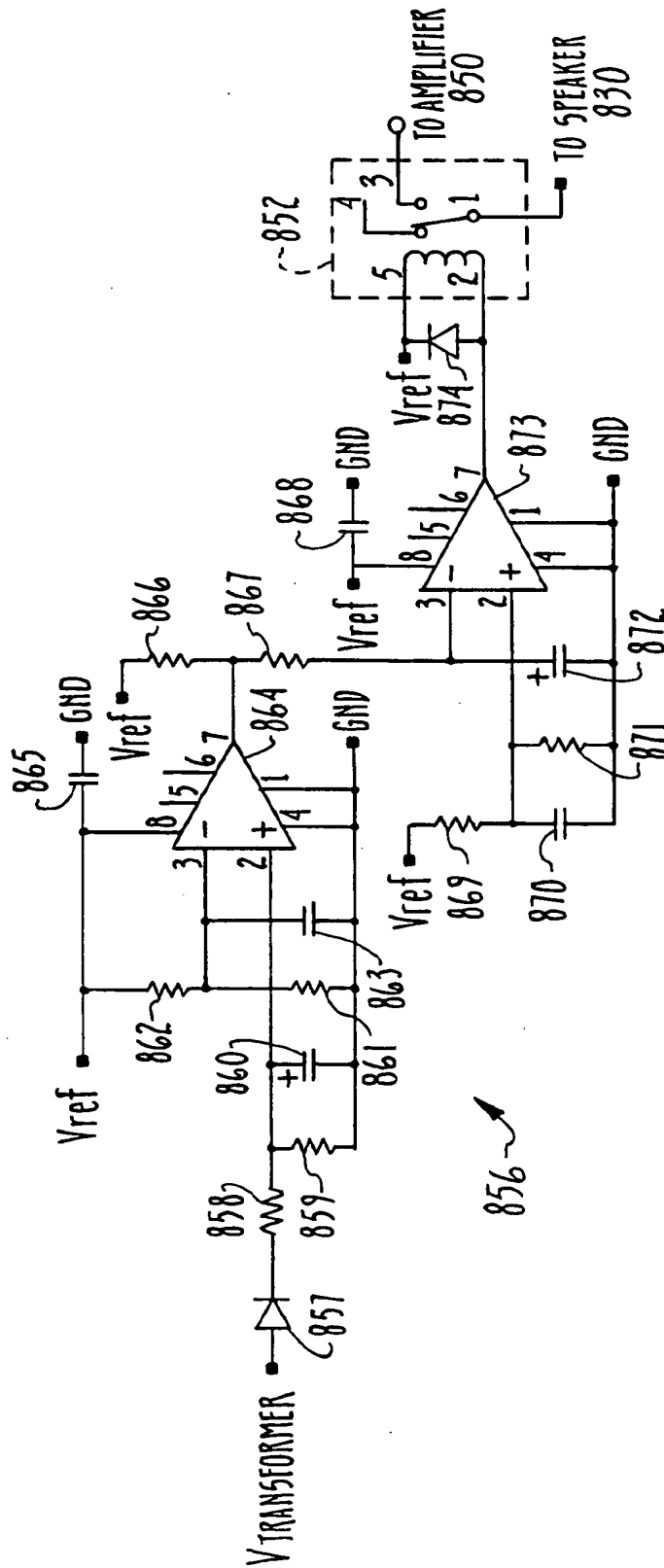


Fig. 23



*Fig-26*

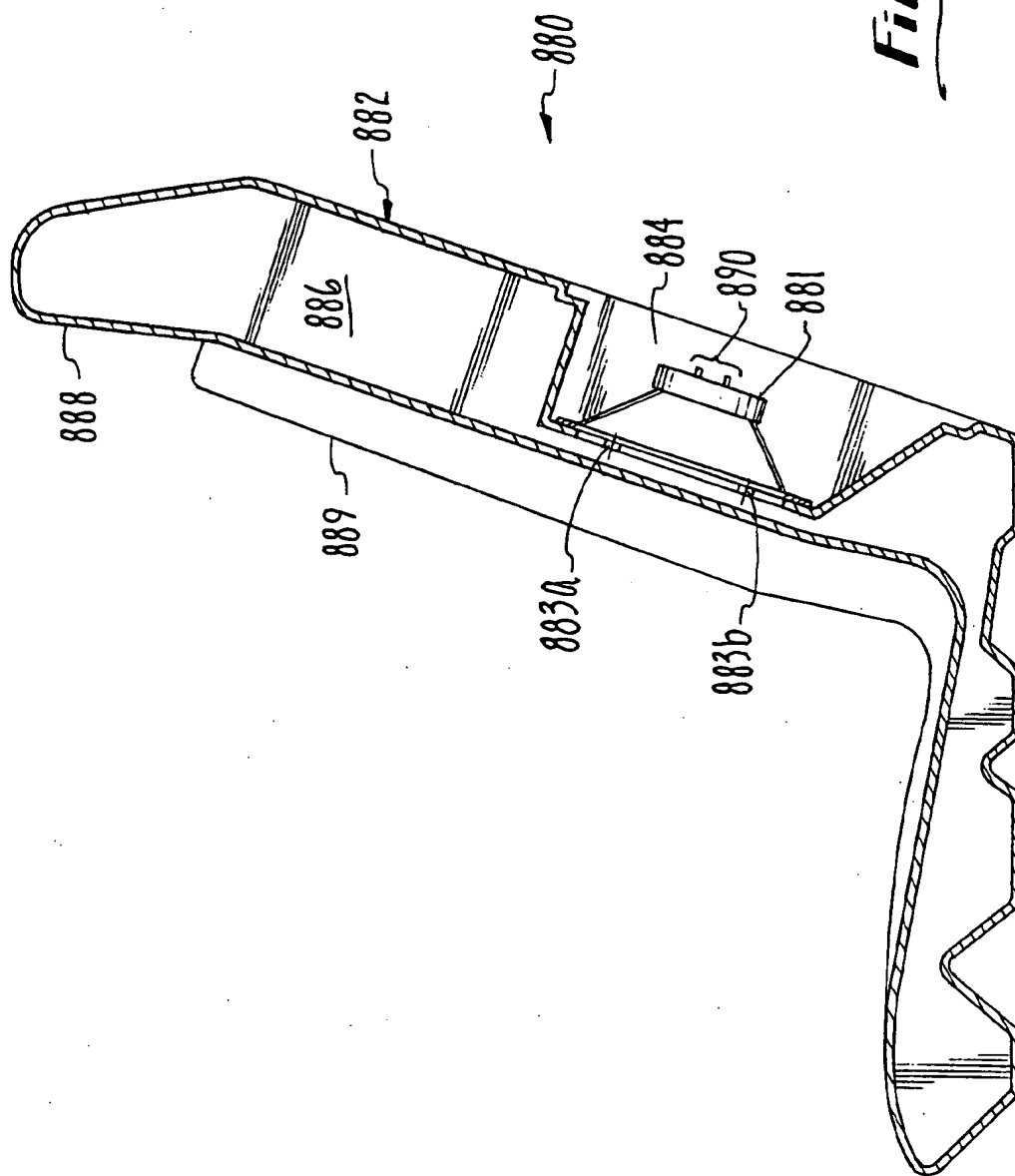


Fig. 27

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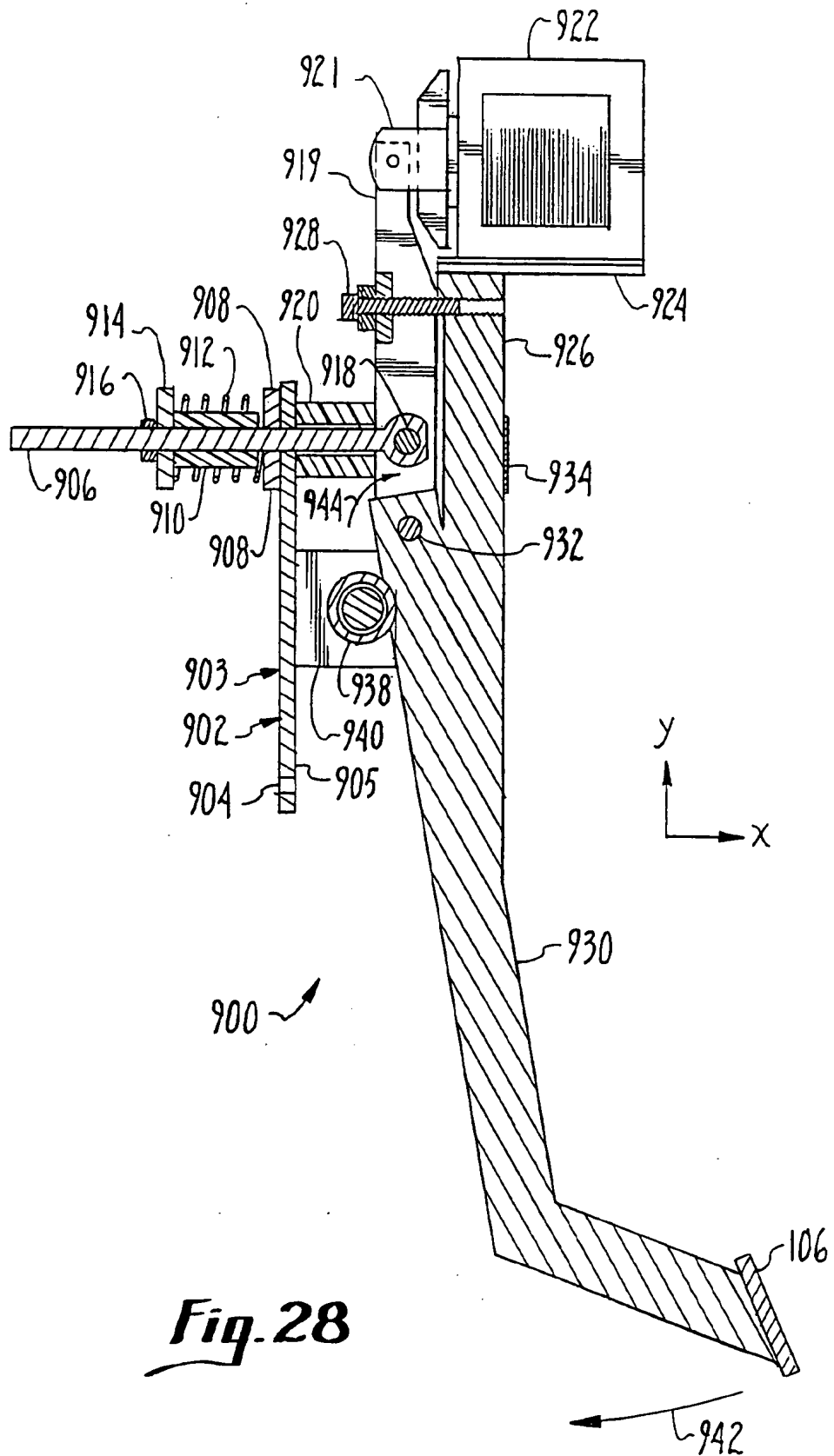



Fig. 28

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 93/04845

A. CLASSIFICATION OF SUBJECT MATTER		
IPC5: G09B 9/04 According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols)		
IPC5: G09B		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO, A1, 9202916 (ATARI GAMES CORPORATION), 20 February 1992 (20.02.92), page 4 - page 5; page 20, line 20 - line 32; figure 1	1,2,3,4,5,6, 9,10,11,12, 13,17
A	--	7,8,14,15,16
X	WO, A1, 9202915 (ATARI GAMES CORPORATION), 20 February 1992 (20.02.92), page 6, line 1 - line 28, figure 1	1,5,6
A	--	2-4,7-17
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search		Date of mailing of the international search report
9 Sept 1993		
Name and mailing address of the ISA/  European Patent Office, P.O. 5818 Patentkan 2 NL-2280 HV Rijswijk Tel. (+31-70) 340-1040, Tx. J1 651 epo nl. Fax: (+31-70) 340-3016		Authorized officer Björn Lindkvist

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 93/04845

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US, A, 4750888 (ALLARD ET AL.), 14 June 1988 (14.06.88), column 2, line 55 - line 68; column 3, line 1 - line 27, figure 1	1
A	--	2-17
X	US, A, 4383827 (FOERST), 17 May 1983 (17.05.83)	1
A	--	2-17
X	US, A, 4150497 (WEBER), 24 April 1979 (24.04.79)	1
A	--	2-17
X	US, A, 4077138 (FOERST), 7 March 1978 (07.03.78), column 1, line 1 - line 57	1,5,9-13,17
A	-----	2-4,14-16

INTERNATIONAL SEARCH REPORT

Information on patent family members

30/07/93

International application No.

PCT/US 93/04845

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		DE-A- 3469325	17/03/88
		EP-A,B- 0145598	19/06/85
		FR-A,B- 2556866	21/06/85
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		JP-A- 56035166	07/04/81
US-A- 4150497	24/04/79	NONE	
US-A- 4077138	07/03/78	DE-A,B,C 2521110	18/11/76
		DE-A- 3032250	01/04/82
		DE-A- 3045841	08/07/82
		JP-C- 1375864	22/04/87
		JP-A- 51141041	04/12/76
		JP-A- 58171073	07/10/83
		JP-B- 61040994	12/09/86